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# Industrial Internet of Things Implementation Strategies with HCI for SME Adoption

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**Abstract:** Industrial Internet of Things (IIoT) is changing the future world and making a big impact on every company. As SMEs are too small to have their own R&D, they may be left behind from the digital disruption age. Academic researches that describe the IIoT implementation strategies with Human Computer Interaction (HCI) for SMEs and adoption items of the strategies are rarely known. This paper reveals the IIoT implementation strategies with new HCI for SMEs in multi-dimensional facets. Analyses of IIoT implementation drivers, strategies, capabilities, and benefits on 30 articles from leading publishers such as Elsevier and Springer in the last 7 years are compared. Furthermore, the adoption items of IIoT implementation strategies are developed and quantitatively analyzed from 325 respondents of leading industries in Thailand manufacturing sector based on Technology, Organization, and Environment (TOE) adoption framework. The findings show that the 4 significant adoption items are lightweight flexibility, non-monotonous task of new HCI, top management's real-time decision making, and market opportunity. These results permit better understanding of how SMEs can learn from the analyzed IIoT implementation strategies with HCI and the analyzed significant adoption items in order to adopt IIoT for their business empowerment, thereby maximizing the IIoT value.

**Keywords:** Industrial Internet of Things; Industry 4.0; IoT; Human-Computer Interaction; Adoption; SME.

## Introduction

Industrial Internet of Things (IIoT) is initially a trend on intelligent automation of the manufacturing industry for large companies [1]. IIoT is a smart assistance system with smart technologies to transform the traditional factory into an intelligent automation level depending on the firm resource. Small and Medium-sized Enterprises (SMEs) do not play any important role in IIoT since they have fewer resources of capital and knowledge than large companies do. However, they are the major economic driving force as they create more Gross Domestic Product (GDP) than their counterpart in many countries. Unfortunately, most of them do not know how to implement IIoT in their own organization with new Human-Computer Interaction (HCI) that supports human more [2]. There are few pointers on the IIoT implementation strategies with HCI for SMEs [3]. SMEs who adopt IIoT as early adopters are also a few and how they adopt IIoT implementation strategies with HCI are scarcely known [4]. These research gaps need to be investigated. The objective of this paper is to find out the IIoT implementation strategies with HCI for SMEs and the adoption items of the strategies. This paper uses a systematic review on prior researches of IIoT implementation strategies for SMEs, analyzes the strategies, and emphasizes HCI. Furthermore, a quantitative analysis for the adoption of SMEs is conducted using a sample of SMEs in Thailand who are early adopters and non-adopters. The survey questionnaire is designed by applying IIoT implementation strategies in the adoption framework based on Technology, Organization, and Environment (TOE) framework. The TOE framework is popular in information technology researches since it covers internal and external adoption factors in 3 dimensions [5]. In Thailand, a national digital transform program called Thailand 4.0 is at its first stage of IIoT implementation focusing on lean automation for SMEs [6]. National Statistical Office of Thailand reports that the number of SMEs who uses IT and has no more than 200 employees is 591, 514 companies. This study will contribute to SME adoption of IIoT implementation strategies with HCI.

## Industrial Internet of Things Implementation Strategies with HCI

### *Industrial Internet of Things*

The world industry has been continuously transformed many times since 18$^{th}$ century [2]. The first industrial revolution started in the United Kingdom from a result of mechanization for water- and steam-powered factory machines in 1784. The second industrial revolution started in the United States from a result of electricfication and assembly line for mass production in 1870. The third industrial revolution started from a result of electronics and Information Technology (IT) for mainframe, personal computers, and computerized production in 1969. Now, the fourth industrial revolution is coming from the emergence of the Internet of Things (IoT) which leads to the Industrial Internet of Things (IIoT) for real-time information support [7]. IoT can be applied at the first stage of IIoT in SMEs to mainly provide architectural connection of heterogeneous equipment in working with human and provide real-time alerts for decision-making under the controllable security of lean IIoT implementation [8].

IIoT has several meanings. It is called Industry 4.0 which was initiated by German government program in 2011 to prepare the country for the disruption power of technology regarding the fourth industrial revolution [1]. It means smart city for developing countries and smart factory [9]. It also means long-term and sustainable plans to develop innovations and make changes. IIoT can be defined by concepts and distinguished by fundamental digitization for limited-resource SMEs or advanced digitization for rich-resource enterprises [10] as shown in Table 1.

Table 1. IIoT concepts, fundamental, and advanced digitization (Adapted from [10]).

| ***IIoT Concepts*** | ***Fundamental digitization*** | ***Advanced digitization*** |
|---|---|---|
| Smart factory | Decentralization | Full automation |
| Cyber Physical Systems | Mass customization | Digital twin |
| New paradigm of HCI | Affordable application | Dynamic value creation networks |

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The IIoT concepts denote smart factory, Cyber Physical Systems, and new paradigm of HCI [10-12]. Smart factory integrates smart technologies in the Internet of Things, Internet of Services, Big data, M2M, and sensored robot with Artificial Intelligence (AI). Cyber Physical Systems (CPS) combine smart physical devices and every stage of the production system to gather digital data for online information exchange with the supply chain autonomously via the internet for administrative decision-making [2]. Although IIoT requires high technology, its work focuses on the adaptation to human needs of both customers and workers. The worker's role, in particular, demands higher skilled than all of the previous industrial revolutions as the processes are revolutionized which have a big influence on HCI [13].

IIoT extraordinary digitization is divided into fundamental and advanced digitization. Fundamental digitization covers the essential IIoT characteristics of decentralization, mass customization, and affordable application [14]. Decentralization is supported by new technologies for decision making, control, and monitoring [15]. Mass customization produces directly to individual customer demand [16]. Affordable application uses smart technologies running in lean production for low cost and better performance [2].

Advanced digitization optimizes the value chains and covers complex features of full automation, digital twin, and dynamic value creation networks that are suitable for large companies. Full automation requires a high intelligent automation level combining AI. Digital twin is a 3D real-time simulation model for a virtual factory using IoT, cloud, big data analytics, 3D modelling, Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) [17]. Thus, it requires high investment and expertise. Production is activated in dynamic value creation networks of the company and partners to create targeted products for customers.

The aforementioned technologies practically call for new HCI to accommodate the IIoT digitization usage, wherein technological capability can be fully exploited in IIoT environment.

### *Human-Computer Interaction*

Human-Computer Interaction (HCI) or Human-Computer Interface endows computer to provide interactive experiences for human. It was first presented in contrast with human dialogue at ASIS Annual Meeting, Boston in 1975 [18]. HCI was disseminated in a computer interaction guideline for user in 1983 [19] to alleviate the traditional clerical and time consuming work. HCI was the interface for human to perform monotonous routine tasks inside factory.

IIoT automation technology components create a paradigm shift of HCI in dynamic interface, multimodal interface, and context-sensitive interface for human to perform non-monotonous tasks inside and outside factory [2]. As such, human has a better future life by playing a higher role of problem solving and decision making to control the manufacturing processes with smart devices. These 3 interfaces work together.

Dynamic interface eases human at work to monitor tasks [13] whereby IIoT enables machine to be self-organized, process tasks, and collaborate with human in real time [20]. Human is changed from an operator to a coordinator who ensures that machine performs the smooth production.

Multimodal interface provides human operators multiple interacting modes of smart input and output in visual, auditory, touch, and motion to communicate with machines in the network [21-22]. Human interacts with multiple mobile devices such as smart glass, camera, and smartphone.

Context-sensitive interface provides different information for different situation to serve human operator needs [21]. Human gets context information related to the situation of human in real time from the smart system of IIoT.

### *IIoT Implementation Strategies*

IIoT defines four different drivers for implementation, namely, technological, innovation, operational, and organizational drivers [23]. Technological driver uses sophisticated technologies. Innovation driver initiates and supports new jobs and business models from change in the value chain. Operational driver handles various production processes at an acceptable cost. Organizational driver is the collaboration of places, facilities, experts, and partners. These are different drivers of IIoT implementation strategies for SME applications.

IIoT capability contains eight keys that involve technical, security, business, efficiency, and human areas [2] as follows. (1) Standardization is a set of platform standards that are agreeable upon partners and customers. (2) System management is a planning method or model to manage the system, components, and data for automation, flexibility, and decision making. (3) Infrastructure is a communication network of computers, smart machines, and facilities to exchange accessible data in the networks. (4) Cyber safety is safety and security of data, human, and robot in the same working environment. (5) Job design requires qualified employees for new work roles of problem solving and decision making. (6) Continuous training is new job learning to get new skills and training measures. (7) Business framework defines work process for interoperability according to the business objectives. (8) Resource efficiency improves system performance to create a new market opportunity and controls cost in human, machine, material, and energy.

## Applications of IIoT Implementation Strategies with HCI for SME Adoption

The traditional IT applications have been replacing gradually by the adoption of IIoT implementation strategies [24]. The strategies provide benefits for SMEs in different factors of technology, top management, market, and government support which influence the adoption. Thirty articles of IIoT implementation strategies with HCI for SME adoption are selected from some leading publishers such as Elsevier and Springer in the last 7 years. The articles are categorized in 13 guideline applications, 8 collaboration applications, and 9 lean automation applications. Each category is reviewed by year.

### *IIoT Guideline Applications*

There are 13 articles that mainly focus on IIoT guideline applications as follows. Wadhwa [16] created a technical guideline strategy for foundry industry. The guideline helped design, check, and manage simple flexible automation which could make product variety, reduce downtime, and control costs. Bauer et al. [25] proposed a work guideline approach with employee focus. The approach was the work organization and workplace designed for young and old employees with high qualifications to work in a long run. Constantinescu et al. [26] proposed a knowledge management guideline to support decision making. The guideline helped create a knowledge retrieval system with selection criteria including SME needs and sustainability. The system provided appropriate requested information to the managerial employees for decision making in real time by checking their individual situation contexts. Uwizeyemungu et al. [27] presented product design for product innovation and relating control variables that supported business growth from manufacturing technology strategy. The variables were firm size, age, and industrial maturity level. Ganzarain and Errasti [28] developed a 3-stage implementation model with process identification for IIoT: (1) vision and company resources definition, (2) roadmap and technology requirements, and (3) training and project implementation. Prinz et al. [29] presented a learning factory strategy describing new employee competences to cope with new environment of high amount of data, new technologies, new processes, and new work roles. Users had to adapt from static work to dynamic work in real-time response from the new network integration. Wank et al. [30] presented a development technology strategy consisting of CPS attributes and development stages in compliance with standards, communication, and data management to increase new market opportunities. Rodic [17] reported an economical simulation model for SMEs. The model increased self-awareness of sensors and actuators to provide real-time data among machines for performance improvement. The multiple sensors tracked warning to human in multimodal interaction to reduce abnormal situation. Rojas et al. [31] proposed a conceptual development strategy for beginners' understanding. The strategy targeted interoperability framework consisting three levels of design: edge level of data collection from smart devices, platform level of data analytics from big data, and enterprise level of management decision making from intelligent applications. Human-robot interaction was provided at the edge level. Schröder [32] presented a data flow management strategy to create new jobs of process innovation and data consistency in production. The strategy was used to exchange data for internal use among departments and external use among partners. Uhlemann et al. [15] proposed a data acquisition guideline by sensored tracking and production machine vision. The guideline helped quantify real-time production data for efficient operation planning. It provided multimodal interface in motion image data using motion detection tools of radar, laser, and lidar. Andulkar et al. [33] reported an implementation guideline for less than 50 employees of SMEs. The guideline showed that IoT was the initial technology of network connectivity for SMEs to start IIoT cost-effectively. Dassisti et al. [34] presented a technology control strategy. The strategy controlled work instructions with new HCI in process automation, quality, and material for business forecast.

All of these guideline applications influenced the adoption of IIoT implementation strategies.

### *IIoT Collaboration Applications*

There are 8 articles that mainly focus on IIoT collaboration applications as follows. Kagermann et al. [2] proposed a collaborative technology transfer for SMEs to cope with IIoT. Large enterprises transferred technology to SMEs and worked together on the same project in multimodal interface. Brettel et al. [35] reported a collaborative network approach to support SMEs. The approach provided machines and facilities for SMEs to implement IIoT and exchange accessible data. Erol et al. [36] proposed a factory center to provide technological infrastructure and experts for SMEs to research and develop their own products. SME users got context-sensitive information from robotic systems to adjust the suitable work environment in the infrastructure. Brending et al. [37] proposed a workplace collaboration strategy providing human to work in a safe distance and position with a multi-purpose low cost robot. Issa et al. [38] addressed a government institution to support collaboration among SMEs by facilitating hardware, software, technical expertise, and information guidance to create new skills for IIoT in a short time. It provided multimodal interface beyond desktop computers in a user-friendly way. Müller and Voigt [1] proposed a collaborative partner approach to support SMEs. The approach provided partners among SMEs to share expertise and technologies of IIoT for mutual sustainability. Machines dynamically worked with human in an agreeable standard platform. Schlegel et al. [39] proposed a factory test environment to provide not only new technologies of equipment, software, network, and energy for SMEs, but also training measures to check employee capability level. Employees got context-sensitive energy information to control energy usage in different locations. Matt et al. [40] proposed an urban production factory in the collaboration with the government and universities for SMEs. It helped SMEs recruit highly qualified young and old full-time and part-time employees to work with high quality of life in the city.

All of these collaboration applications influenced the adoption of IIoT implementation strategies.

### *IIoT Lean Automation Applications*

There are 9 articles that mainly focus on IIoT lean automation applications as follows. Radziwon et al. [3] presented a customer-oriented lean automation approach for SMEs. The approach utilized full machines to manufacture several different products and applied new technologies to reduce delivery time of customized products for market opportunity which increased the adoption of IIoT implementation strategies. A context-sensitive application was interfaced with human to provide real-time information based on user's location. Hirsch-Kreinsen [41] presented a lean and lightweight automation approach for SMEs. The approach focused on lightweight flexibility of automation technology which was simple and inexpensive to implement a low cost factory and increased the adoption of IIoT implementation strategies. Sanders et al. [42] proposed four lean manufacturing factors for SMEs. The factors adjusted with automation technologies to suit in IIoT were supplier factor, customer factor, process factor, and employee factor. The automation technologies changed job design from routine tasks to non-monotonous tasks of new HCI which led to the adoption of IIoT implementation strategies. Grube et al. [43] presented a lean automation approach with plug and produce for SMEs. The approach of assembly lines could install reconfigurable components from smart technology which were simple, inexpensive, and led to the adoption of IIoT implementation strategies. Mrugalska and Wyrwicka [44] proposed five lean production principles for use by smart products in a smart factory. They were (1) lean value from product identification, (2) lean value from process identification which let top management adjust the business framework and increased the adoption of IIoT implementation strategies, (3) lean flow from factory review, (4) lean pull from select strategy, and (5) lean perfection from improvement. Users employed context-sensitive response from the production system to create smart products. Müller et al. [45] presented a lean document tool for SMEs. The tool kept, modified CAD production drawings, and sent to the parties involved in multimodal interface. This tool helped top management make a real-time decision which increased the adoption of IIoT implementation strategies. Frontoni et al. [46] proposed a lean automation approach using smart technologies in multimodal interface with web data through smartphone, smart glass, and smart watch to get production optimization with real-time information. This increased the adoption of IIoT implementation strategies. Kumar et al. [47] proposed a lean production monitoring approach for SMEs. The approach used cloud manufacturing technology to collect production process for monitoring and communicating status among departments to keep low inventory level which increased the adoption of IIoT implementation strategies. Uriarte et al. [48] proposed a lean automation approach using a simulation model to improve the system performance in context-sensitive interface. The approach required government support for new skills which was uncertain and decreased the adoption of IIoT implementation strategies.

## Adoption Framework and Hypotheses

The reviewed IIoT applications above show benefits of IIoT strategies for SMEs in different factors of technology, top management, market opportunity, and government support which influence the IIoT implementation strategies adoption. These factors involve technology, organization, and environment aspects which can be extended and utilized to the Technology, Organization, and Environment (TOE) adoption framework in order to address the adoption of SMEs. Previously, the TOE adoption framework was developed by DePietro et al. [5] in 1990 for employee adoption in IT which covered areas inside and outside the organization. The traditional Technology Acceptance Model (TAM) adopts a new technology on perception of usefulness, ease of use, and intention to use [49]. The TOE framework adopts a new technology in 3 dimensions of technology, organization, and environment and it is applied in non-traditional applications which importantly use internet such as e-commerce [50] and IIoT [4].

For IIoT implementation strategy adoption, SMEs practically implemented IIoT in their own existing production system using lean automation strategy [24] to sustain their business confidently. In addition, Thailand 4.0 focuses on IIoT lean automation strategy for SMEs more than guideline and collaboration strategies. This research applies TOE in IIoT adoption based on the reviewed IIoT lean automation applications above.

### *Technology Dimension*

Technology dimension refers to factors in technology that the firm gets from IIoT adoption in terms of relative advantage attributes for the operation. Flexibility simplifies a low level of automation in the factory operation for SMEs [51]. New HCI job design sets up new HCI tasks using smart devices to create new work roles, qualified employees, and non-monotonous tasks for human [4]. Cost reduction includes reconfigurable component, production optimization, inventory reduction [52]. More attributes of relative advantages include technology integration which covers network connectivity, accessible data, and interoperability [52], security protection, technology infrastructure [53], establishment of data consistency [4], and establishment of standards and measures.

The previous articles identified 5 items in technology dimension that increased the adoption of IIoT implementation strategies for SMEs, namely, lightweight flexibility, reconfigurable component, production optimization, non-monotonous task of new HCI, and inventory reduction based on the IIoT lean automation applications above.

Lightweight flexibility is argued that it applies automation technology which is simple and inexpensive and offers flexibility to increase the adoption of IIoT implementation strategies [41]. Lightweight flexibility is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H1. Lightweight flexibility positively influences the adoption of IIoT implementation strategies.

Reconfigurable component is argued that it reconfigures inexpensive component from smart technology and offers cost reduction to increase the adoption of IIoT implementation strategies [43]. Reconfigurable components is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H2. Reconfigurable component positively influences the adoption of IIoT implementation strategies.

Production optimization is argued that it uses smart technologies in multimodal interface to optimize resource efficiency in production and offers cost reduction to increase the adoption of IIoT implementation strategies [46]. Production optimization is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H3. Production optimization positively influences the adoption of IIoT implementation strategies.

Non-monotonous task of new HCI is argued that it changes routine tasks and offers job design of new HCI tasks to increase the adoption of IIoT implementation strategies [42]. Non-monotonous task of new HCI is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H4. Non-monotonous task of new HCI positively influences the adoption of IIoT implementation strategies.

Inventory reduction is argued that it applies cloud manufacturing technology to keep low inventory level for resource efficiency and offers cost reduction to increase the adoption of IIoT implementation strategies [47]. Inventory reduction is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H5. Inventory reduction positively influences the adoption of IIoT implementation strategies.

### *Organization Dimension*

Organization dimension refers to factors in internal organization that the firm gets from IIoT adoption in terms of firm size [4] and top management who supports real-time decision making and process identification to conduct the business [54].

The previous articles identified 2 items in organization dimension that increased the adoption of IIoT implementation strategies for SMEs, namely, top management's real-time decision making and top management's process identification based on the IIoT lean automation applications above.

Top management's real-time decision making is argued that the involvement of top management who utilizes system management tool offers real-time decision to increase the adoption of IIoT implementation strategies [45]. Top management's real-time decision making is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H6. Top management's real-time decision making positively influences the adoption of IIoT implementation strategies.

Top management's process identification is argued that the involvement of top management who is responsible for adjusting business framework offers identified lean process to increase the adoption of IIoT implementation strategies [44]. Top management's process identification is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H7. Top management's process identification positively influences the adoption of IIoT implementation strategies.

### *Environment Dimension*

Environment dimension refers to factors in external environment that the firm gets from IIoT adoption in terms of market opportunity and government support. Market opportunity increases new markets of mass customization [4]. Government support provides continuous training for SMEs to learn new skills [52].

The previous articles identified 2 items in environment dimension that influenced the adoption of IIoT implementation strategies for SMEs, namely, market opportunity and government support for new skills based on the IIoT lean automation applications above.

Market opportunity is argued that it applies new technologies to reduce delivery time of customized products and offers opportunity in the market to increase the adoption of IIoT implementation strategies [3]. Market opportunity is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H8. Market opportunity positively influences the adoption of IIoT implementation strategies.

Government support for new skills is argued that government who supports continuous training but might be uncertain due to the budget loss offers new skills to decrease the adoption of IIoT implementation strategies [48]. Uncertain government support for new skills is added to the adoption framework. The corresponding hypothesis is proposed as follows.

H9. Uncertain government support for new skills negatively influences the adoption of IIoT implementation strategies.

The proposed framework of IIoT implementation strategies for SME adoption consists of 9 adoption items as shown in Figure 1.

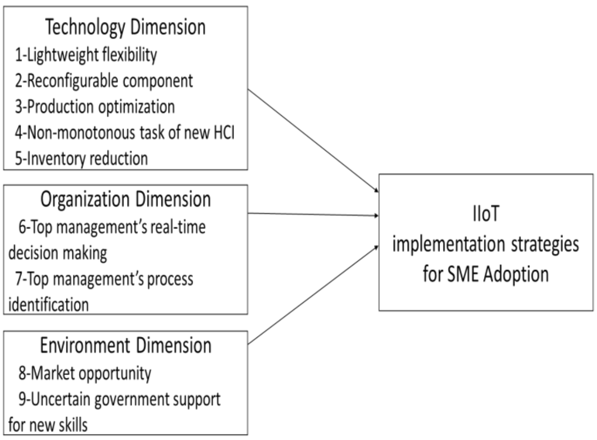


Figure 1. Proposed IIoT adoption framework (Adapted from [4]).

## Research Methodology

The research methods are systematic review and quantitative method. Systematic review is used to review 30 articles in IIoT implementation strategies with HCI for SMEs from some leading publishers such as Elsevier and Springer in the last 7 years. For quantitative method, this research uses 591, 514 SMEs who have IT systems in Thailand as the population. The selection criteria of purposive sampling were the firm size of 100 employees up and 4 different leading industries in food, electronics, chiller, and machinery. The sample is early adopters and non-adopters of IIoT in the manufacturing sector. The total number of 325 employees including management is selected to answer a survey questionnaire with a demographic section and a five-point Likert scale section of 9 items according to the adoption items of IIoT implementation strategies from Figure 1 between August and October 2018. The clarity and validity of the questionnaire is checked by 3 IT experts before to ensure that SMEs in the manufacturing sector answer each item understandingly.

The sample size of 325 respondents includes 275 adopters and 50 non-adopters. Quantitative analyses are conducted using SPSS for Windows tools of descriptive statistics to analyze the demographics and logistic regression to assess the adoption items of IIoT implementation strategies. All 9 adoption items are independent variables and they do not relate to each other. IIoT implementation strategies for SME adoption is dependent variable consisting of 1 for adoption and 0 for non-adoption. Logistic regression is required for the binary dependent variable and supports the assumptions of hypothesis test.

## Results

The systematic review results of IIoT implementation strategies with HCI for SMEs are categorized in guideline applications, collaboration applications, and lean automation applications. Detailed analysis of those are compared by IIoT implementation driver, strategy, capability, and benefit in different factors (factor for TOE) as shown in Table 2, Table 3, and Table 4, respectively. The Benefits in IIoT implementation strategies implied to TOE from 30 applications are summarized in 3 dimensions as shown in Table 5.

Table 2 summarizes the analysis of IIoT implementation strategies with HCI in 13 guideline applications.

Table 2. Analysis of IIoT implementation strategies – Guideline strategy.

| *Driver* | *IIoT strategy* | *Capability* | *Benefit (Factor for TOE)* | *Reference* |
|---|---|---|---|---|
| **Guideline application** | | | | |
| Technological | Technical guideline | System management | Lightweight flexibility | [16] |
| | Technology strategy | System management | Control variable in firm size | [27] |
| | Development strategy | Resource efficiency | Market opportunity | [30] |
| | Implementation guideline | System management | Network connectivity | [33] |
| | Control strategy | System management | Production optimization | [34] |
| Organizational | Work guideline with employee focus | Job design | Qualified employee of new HCI | [25] |
| | Knowledge management guideline | System management | Top management's real-time decision making | [26] |
| | Implementation model | Business framework | Top management's process identification | [28] |
| | Learning factory strategy | Job design | Work role of new HCI | [29] |
| | Conceptual development | Business framework | Interoperability | [31] |
| Innovation | Data flow strategy | System management | Data consistency | [32] |
| Operational | Economical simulation model | System management | Production optimization | [17] |
| | Data acquisition guideline | System management | Production optimization | [15] |

Table 3 summarizes the analysis of IIoT implementation strategies with HCI in 8 collaboration applications.

Table 3. Analysis of IIoT implementation strategies – Collaboration strategy.

| *Driver* | *IIoT strategy* | *Capability* | *Benefit (Factor for TOE)* | *Reference* |
|---|---|---|---|---|
| **Collaboration application** | | | | |
| Technological | Collaborative Technology transfer | Resource efficiency | Technology transfer | [2] |
| | Collaborative guidance | Continuous training | Government support for new skills | [38] |
| | Collaborative test environment | Continuous training | Training measure | [39] |
| Organizational | Collaborative network | Infrastructure | Accessible data | [35] |
| | Collaborative factory center | Infrastructure | Suitable work environment | [36] |
| | Collaborative workplace | Cyber safety | Safe distance and position | [37] |
| | Collaborative partner | Standardization | Standard platform | [1] |
| | Collaborative urban production | Job design | Qualified employee of new HCI | [40] |

Table 4 summarizes the analysis of IIoT implementation strategies with HCI in 9 lean automation applications utilized to the proposed IIoT adoption framework of Figure 1.

Table 4. Analysis of IIoT implementation strategies – Lean automation strategy.

| *Driver* | *IIoT strategy* | *Capability* | *Benefit* | *Reference* |
|---|---|---|---|---|

| | | | *(Factor for TOE)* | |
|---|---|---|---|---|
| **Lean automation application** | | | | |
| Technological | Lean and lightweight automation | System management | Lightweight flexibility | [41] |
| | Four lean manufacturing factors | Job design | Non-monotonous task of new HCI | [42] |
| | Lean automation with plug and produce | System management | Reconfigurable component | [43] |
| | Lean automation | Resource efficiency | Production optimization | [46] |
| | Lean production monitoring | Resource efficiency | Inventory reduction | [47] |
| Organizational | Five lean principles | Business framework | Top management's process identification | [44] |
| | Lean information tool | System management | Top management's real-time decision making | [45] |
| Operational | Customer-oriented lean automation | Resource efficiency | Market opportunity | [3] |
| | Lean automation with simulation | Continuous training | Government support for new skills | [48] |

Table 5 summarizes the analysis of benefits in IIoT implementation strategies implied to TOE from 30 applications.

Table 5. Analysis of benefits in IIoT implementation strategies implied to TOE – All strategies.

| ***Benefit (Factor for TOE)*** | ***Technology*** | ***TOE in 3 dimensions Organization*** | ***Environment*** |
|---|---|---|---|
| Lightweight flexibility | Flexibility | | |
| Work role of new HCI | New HCI job design | | |
| Qualified employee of new HCI | New HCI job design | | |
| Non-monotonous task of new HCI | New HCI job design | | |
| Reconfigurable component | Cost reduction | | |
| Production optimization | Cost reduction | | |
| Inventory reduction | Cost reduction | | |
| Network connectivity | Technology integration | | |
| Accessible data | Technology integration | | |
| Interoperability | Technology integration | | |
| Safe distance and position | Security protection | | |
| Technology transfer | Technology infrastructure | | |
| Suitable work environment | Technology infrastructure | | |
| Data consistency | Establishment of data consistency | | |
| Training measure | Establishment of standards and measures | | |
| Standard platform | Establishment of standards and measures | | |
| Top management's process identification | | Top management support | |
| Top management's real-time decision making | | Top management support | |

Table 5. Analysis of benefits in IIoT implementation strategies implied to TOE – All strategies (continued).

| ***Benefit*** | ***Technology*** | ***TOE in 3 dimensions*** | ***Environment*** |
|---|---|---|---|

| *(Factor for TOE)* | *Organization* | |
|---|---|---|
| Control variable in firm size | Firm size | |
| Market opportunity | | Market opportunity |
| Government support for new skills | | Government support |

For quantitative analysis, the reliability test result of all adoption items in the questionnaire has high reliability (9 adoption items, 0.90). Cronbach's alpha values of TOE adoption framework in 3 dimensions are: technology dimension (5 adoption items, 0.84), organization dimension (2 adoption items, 0.70), and environment dimension (2 adoption items, 0.70). The cronbach's alpha values in all dimensions are acceptable and make the questionnaire reliable. The completed questionnaire responses totaled 280 respondents (240 adopters and 40 non-adopters) with 86.15% response rate. For demographic data from manufacturers of leading industries shown in Table 6, the 240 adopters are at the first stage of IIoT implementation. The food manufacturers deploy IoT in a smart system to show a real-time production schedule for operators to produce sausage properly. The electronic manufacturers deploy a smart system to diagnose and alert the abnormal status of inverters in customer sites for supervisor engineers in real time. The chiller manufacturers deploy a smart system to alert production managers how many chillers the machines produce in real time. The 40 non-adopters are machinery manufacturers and produce boilers. The number of adopter respondents (85.71%) is more than the number of non-adopter respondents (14.29%).

The adoption questionnaire results of IIoT implementation strategies are analyzed and compared using mean and standard division (SD) as shown in Table 7. Among IIoT implementation strategy adoption answers, adoption item 6 of top management's real-time decision making has the highest mean (mean 4.74, SD 0.61) while adoption item 3 of production optimization has the lowest mean (mean 4.40, SD 0.76). Adoption item 8 of market opportunity has the second highest mean (mean 4.69, SD 0.63) and adoption item 5 of inventory reduction has the third highest mean (mean 4.64, SD 0.77). All adoption items have no multicollinearity in the correlation coefficients ($r < 0.80$).

Logistic regression is conducted to assess the 9 adoption items. The omnibus test result is significant (Chi-square = 150.65, p-value = 0.00). The model summary test results (Cox & Snell $R^2 = 0.42$, Nagelkerke $R^2 = 0.74$) are acceptable to represent the proportion of variance in the logistic regression model 42% and 74%, respectively. The Hosmer and Lemeshow goodness-of-fit test result (Chi-square = 9.25, p-value = 0.24) is acceptable to have the proposed model.

The logistic regression model of IIoT implementation strategies for SME adoption shows B coefficients and p-values of each adoption item included in the model in Table 7. The four adoption items significant at the 5 percent level are lightweight flexibility (LF), non-monotonous task of new HCI (NT), top management's real-time decision making (TR), and market opportunity (MO). The most significant adoption item is lightweight flexibility (LF, highest B coefficient = 2.26). Four hypotheses of H1, H4, H6, and H8 are accepted. All of them are proved to have the positive influence to the likelihood of the adoption of IIoT implementation strategies for SMEs. The five non-significant adoption items are reconfigurable component (RC), production optimization (PO), inventory reduction (IR), Top management's process identification (TP), and uncertain government support (UG). Five hypotheses of H2, H3, H5, H7, and H9 are not accepted. The logit response function is shown as follows.

$$Z = -25.23 + 2.26LF + 1.24NT + 1.58TR + 1.48MO$$

The four significant adoption items have value Exp(B) > 1 (Exp(B) of LF = 9.54, NT = 3.45, TR = 4.85, and MO = 4.39) showing that they increase the likelihood of the adoption. The value of LF (highest Exp(B)) must be the most important that makes the likelihood of adoption more than the likelihood of non-adoption. The value of NT (lowest Exp(B)) must be the least important that makes the likelihood of adoption more than the likelihood of non-adoption. The proposed logistic regression model can be used to assess the adoption of IIoT implementation strategies for SMEs.

Table 6. Demographics of IIoT implementation strategy adoption (n=280).

| *Description* | *Respondents* | *Percentage* |
|---|---|---|
| **Leading industry of manufacturers** | | |
| Food | 78 | 27.86 |
| Electronics | 89 | 31.78 |
| Chiller | 73 | 26.07 |
| Machinery | 40 | 14.29 |
| **Respondent information** | | |
| Number of adoption | 240 | 85.71 |
| Number of non-adoption | 40 | 14.29 |
| Male | 191 | 68.21 |
| Female | 89 | 31.79 |
| Number of management | 38 | 13.57 |
| Number of staff | 242 | 86.43 |

Table 7. IIoT implementation strategies for SME adoption results (n=280).

| *Adoption item* | *Mean SD* | *B* | *S.E.* | *Wald* | *p-value* | *Exp(B)* | *Hypothesis result* |
|---|---|---|---|---|---|---|---|
| **Technology dimension** | | | | | | | |
| 1. Lightweight flexibility (LF) is likely to influence the adoption of IIoT implementation strategies [41]. | 4.46 0.70 | 2.26 | 0.73 | 9.69 | 0.00* | 9.54 | Accepted |
| 2. Reconfigurable component (RC) is likely to influence the adoption of IIoT implementation strategies [43]. | 4.42 0.73 | -0.90 | 0.67 | 1.81 | 0.18 | 0.41 | |
| 3. Production optimization (PO) is likely to influence the adoption of IIoT implementation strategies [46]. | 4.40 0.76 | 0.50 | 0.66 | 0.56 | 0.45 | 1.65 | |
| 4. Non-monotonous task of new HCI (NT) is likely to influence the adoption of IIoT implementation strategies [42]. | 4.55 0.71 | 1.24 | 0.61 | 4.06 | 0.04* | 3.45 | Accepted |
| 5. Inventory reduction (IR) is likely to influence the adoption of IIoT implementation strategies [47]. | 4.64 0.77 | 0.64 | 0.78 | 0.66 | 0.42 | 1.89 | |
| **Organization dimension** | | | | | | | |
| 6. Top management's real-time decision making (TR) is likely to influence the adoption of IIoT implementation strategies [45]. | 4.74 0.61 | 1.58 | 0.60 | 6.96 | 0.01* | 4.85 | Accepted |
| 7. Top management's process identification (TP) is likely to influence the adoption of IIoT implementation strategies [44]. | 4.51 0.69 | -0.64 | 0.74 | 0.75 | 0.39 | 0.53 | |

Table 7. IIoT implementation strategies for SME adoption results (n=280) (continued).

| *Adoption item* | *Mean SD* | *B* | *S.E.* | *Wald* | *p-value* | *Exp(B)* | *Hypothesis result* |
|---|---|---|---|---|---|---|---|
| **Environment dimension** | | | | | | | |
| 8. Market opportunity (MO) is likely to influence the adoption of IIoT implementation strategies [3]. | 4.69 0.63 | 1.48 | 0.64 | 5.29 | 0.02* | 4.39 | Accepted |
| 9. Uncertain government support (UG) for new skills is likely to influence the adoption of IIoT implementation strategies [48]. | 4.49 0.75 | -0.04 | 0.49 | 0.01 | 0.94 | 0.97 | |
| Intercept (Constant) | | -25.23 | 5.02 | 25.22 | 0.00 | 0.00 | |

## Conclusion

This research aims to determine the IIoT implementation strategies with HCI for SMEs and the adoption items of the strategies applying TOE adoption framework. The IIoT implementation strategies with new HCI for SMEs are reviewed by year and categorized in guideline applications, collaboration applications, and lean automation applications. Each category is compared in multiple dimensions including benefits of IIoT (factor for TOE).

The findings of the three categories in 30 reviewed applications are summarized to reveal the implication of IIoT implementation strategies regarding benefit to TOE into 3 dimensions. Benefits in flexibility, new HCI job design, cost reduction, technology integration, security protection, technology infrastructure, establishment of data consistency, and establishment of standards and measures are implied to technology dimension. Benefits in top management support and firm size are implied to organization dimension. Benefits in market opportunity and government support are implied to environment dimension.

Nine adoption items developed from factors for TOE based on the IIoT lean automation applications are lightweight flexibility, reconfigurable component, production optimization, non-monotonous task of new HCI, inventory reduction, top management's real-time decision making, top management's process identification, market opportunity, and uncertain government support for new skills. They are analyzed by collecting questionnaires from 280 completed respondents of 4 leading industries in manufacturing sector of Thailand. The highest mean score of adoption items is top management's real-time decision making. Logistic regression is conducted to assess the adoption items and highlight four significant items that positively influence the adoption of IIoT implementation strategies for SMEs including non-monotonous task of new HCI. Having lightweight flexibility as the most significant adoption item, the limited-resource SMEs can decide to adopt the IIoT implementation strategies in lean and less complexity supported by previous research [55] at less cost. SMEs can gain more in non-monotonous task, real-time decision making, and market opportunity from other significant adoption items for the participation in the IIoT era.

The findings of the four significant adoption items in positive impact reveal the benefits that can empower SME business. Lightweight flexibility which has the highest impact on the adoption of IIoT implementation strategies is suggested as a way to implement simple and inexpensive IIoT automation technology in factory for possible achievement. Top management's real-time decision making and market opportunity have modest impact on the adoption of IIoT implementation strategies. Top management's real-time decision making is suggested as essential management support with real-time IIoT information in responding to customer needs at the right time for the right business direction. Market opportunity is suggested as the opportunity of serving demand for mass customization for the increase of business sustainability. Non-monotonous task of new HCI which has the lowest impact on the adoption of IIoT implementation strategies is suggested as the new job design for human in problem solving task to control routine tasks of smart devices for quick operation.

The analyzed IIoT implementation strategies with HCI for SMEs and the significant adoption items are preliminary directions for SMEs to understand before implementing IIoT in a proper manner.

This study is limited to a sample in 4 leading industries of food, electronics, chiller, and machinery. Future research should focus on more industries to confirm the outcome.

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