IoT in Food Supply Chain Quality Management: Strategic Recommendation for IoT Service Providers

[1]Pakorn Opasvitayarux, [2*]Siri-on Setamanit,
[3]Krisana Visamitanan, and [4]Nuttapol Assarut
[1]Graduate School, Chulalongkorn University, Bangkok, Thailand
[2, 3, 4]Chulalongkorn Business School, Chulalongkorn University, Bangkok, Thailand
*Corresponding Author
Email: [1]pakorn.opa@gmail.com, [2]siri-on@cbs.chula.ac.th
[3]krisana@cbs.chula.ac.th, [4]nuttapol@cbs.chula.ac.th

Received November 1, 2022; **Revised** December 4, 2022; **Accepted** December 19, 2022

Abstract

The Internet of Things is useful for both consumers and manufacturers due to several obvious benefits, such as tracking quality and authentication, capturing environmental changes, automatically alerting when incidents occur, and so on. Thus, the Internet of Things has become an important tool, especially for manufacturers and their supply chain networks, to collaboratively process and monitor activities in real-time. Previous studies of IoT in the supply chain investigated the factors that aided or hindered end-user adoption of this technology, including manufacturers in a variety of industries. These past studies aimed to suggest the end users on how to adjust themselves to adopt IoT. In this study, the authors focused on providing the strategic recommendation for the IoT service providers that was still insufficiently shown in the current literature. The data was collected through a survey of 197 food processing manufacturers registered with the Thai government. The result indicated that the manufacturers expected to increase the usage of quality management IoT (QM IoT) from 74 firms (37.6%) to 189 firms (95.9%) in the future. The results of this research could help the IoT service providers better offer services that match the end users' preferences, including in selecting target customers, areas of focus (SCOR views), and priority of activity.

Keywords: Internet of Things; Quality Management; Food Supply Chain Management; SCOR; Strategic Recommendation

Introduction

The food that we consumed daily might be traveled in distance from the producers scattered in several countries. Both producers and consumers like us are highly aware of the quality and safety of the products. In the past, there were several food quality and safety incidents, such as chemical elements in eggs, milk powder, and other kinds of food (Ying & Fengquan, 2013), in which could create health and economic concerns. The introduction of the Internet of things (IoT) could help track and trace the product quality in real-time without human intervention (Kevin, 2009). There were several research that mentioned the benefits of IoT in managing quality in the food supply chain. For sourcing, the electric nose helped accept or reject the incoming raw materials (Peres et al., 2007), while quality management IoT could also determine the authentication information of Halal ingredients (Ahmad Tarmizi et al., 2020). For making, the IoT could track the humidity, temperature, product handling, or ripening status in manufacturers (Pérez-Aloe et al., 2007). For delivering, QM IoT could monitor the quality of the product during the transporting, storing, and vending; thus, the environmental changes could be captured and alerted to the users (Mattoli et al., 2009). For returning, IoT could help the firms realize the issues and recall the goods immediately when incidents unexpectedly happened (Kumar & Budin, 2006). For planning, the amount and period for the fertilizer or harvesting could be determined by using IoT (Wahabzada et al., 2016; Walter et al., 2017).

Bain & Company conducted a survey with the IoT vendors and potential customers in the US and worldwide. The results showed that approximately 90% of them were still in planning and proof-of-concept stage in using IoT (Bosche et al., 2016). Similarly, McKinsey also found out that the current IoT users had not yet fully exploited the data collected from their IoT (Manyika et al., 2015). On global perspectives, the result showed that the IoT usage in the industries were still limited, while the data collected from IoT was not fully utilized. In Thailand, the Digital Economy Promotion Agency (DEPA) indicated that the adoption of IoT was still at the beginning stage (Digital Economy Promotion Agency, 2019). In addition, the National Broadcasting and Telecommunication Commission (NBTC) has called an attention to fasten the adoption of IoT to maintain the competitive advantages for Thailand among other countries (National Broadcasting Telecommunications Commission, 2017). The research showed that the economic impacts in 2025 from the 3 business sectors that mostly related to the food supply chain, including the factory, logistics, and retail represented more than 50% of the total potential positive business impact of IoT in Thailand. Thus, this created an opportunity to conduct this research to understand the areas of the quality management Internet of things (QM IoT) that the food industry expected to use in the future.

Instead of studying on the influencing factors for manufacturers to adopt QM IoT, the results from this research aimed to provide the strategic recommendation for the IoT service providers in providing QM IoT services to the food processing industry. Therefore, the IoT service providers could better offer the QM IoT service that matched with the manufacturers' preferences. As a result, the attention on the IoT adoption by the Thai government (Digital Economy Promotion Agency, 2019; National Broadcasting Telecommunications Commission, 2017) could potentially be fasten by the strategic recommendation given from this research. The opportunity for the positive business impacts could also be found accordingly.

The research used quantitative method. The authors collected the data through online surveys from the members of food processing manufacturers that registered with the Food Processing Industry Club, the Federation of Thai Industry (Food Processing Industry Club, 2021). The descriptive statistical tools, such as average numbers and percentage, were used to explain, compare, and analyze the data that were collected during 1 Sep 2021 – 31 Dec 2021.

Research Objective

To ensure that the service providers could better offer the QM IoT services to the food processing manufacturers, the authors constructed the objective as to provide the strategic recommendation for the IoT service providers in providing QM IoT services.

Literature Review

There are three sections that were covered in the literature. The first two sections gave solid background on the quality management in food supply chain and the definition and architecture of the Internet of things. These first two areas led to the third area, which was the use of quality management Internet of things (QM IoT) in food supply chain through SCOR view. The current literature on QM IoT in each SCOR area was intensively discussed.

1. The quality management in food supply chain

Generally, the quality management referred to "the use of management techniques and tools to achieve consistent quality of products and services" (Al-Rub et al., 2020). In food related context, the quality management referred highly on the ability to follow the food movement through several stages of the food supply chain, including production, processing, and distribution (Codex Alimentarius Commission, 2022).These activities were called as traceability, in which could be categorized into three groups, including the back traceability (from suppliers), the internal traceability (internal process), and forward traceability (from clients) (Pérez-Aloe et al., 2007).

It was essential that the food manufacturers and their supply chain networks had better understand the food quality and safety requirements, and perform accordingly because the consumers, including babies, children, adults, elderly, patients, or even pets could safely and confidently consume those food. GS1, a not-for-profits international organization, promoted the use of IoT to improve the traceability and visibility, especially in the food services (GS1, 2017). Thus, the introduction of IoT could help the food supply chain to collect, trace, and share the food quality and safety in real-time.

2. The definition and architecture of the Internet of things

The Internet of things (IoT) was firstly created in 1999 by Kevin Ashton who was working on a research project at the Massachusetts Institution of Technology's AutoID center by linking the Radio Frequency Identification (RFID) in Proctor & Gamble's supply chain (Kevin, 2009). There were four layers of IoT, including sensing layer, network layer, data management layer, and analytics layer (Dweekat et al., 2017). These 4 layers of IoT could help the firms to capture the data from 'things' without human intervention, including tracking and tracing, generating warning on replacing, repairing, or recalling, and also helping reducing waste, loss, and costs (Kevin, 2009).

The first layer of IoT was a sensing layer. It referred to the objects or things augmented with sensors, actuators, or the data identification and capture technologies, such as RFID (Carcary et al., 2018; Dweekat et al., 2017). It was used to capture the motion, environmental, and position changes. Then, the data captured in this layer was delivered via the second layer, which was the network layer. The wildly-known network connection included short-range device connection (WiFi, Bluetooth, Z-Wave, and ZigBee), Low-Power Wide-Area (LPWA) network connection (SigFox, LoRa, LTE-M, NB-IoT), and the satellite network connection (GPS) (Khunboa, 2019; National Broadcasting Telecommunications Commission, 2017). Thirdly, the data management layer stored, filtered, cleaned transformed, and aggregated the data from the previous layer (Dweekat et al., 2017; Sheng et al., 2010). This layer worked with the fourth layer – analytic layer – that provided application, such as the Decision Support Systems (DDS), Enterprise Information System (EIS), Service Oriented Architecture (SOA), and Everything as a Service (XaaS) (Pang et al., 2015).

IoT could help the firms strengthen the performance of several activities without human intervention. Thus, the quality and safety of the food could also be tightened from its benefits. In the next section, the current research on the use of IoT in quality management in food supply chain were examined based on the SCOR view.

3. The use of quality management Internet of things in food supply chain through SCOR view

The current literature discussed on the benefits of IoT on a particular area depending on each researcher's focus. In this research, the authors discussed on the quality management Internet of things (QM IoT) based on 5 SCOR views, including source, make, deliver, return, and plan. Each of the areas was discussed respectively.

Source: QM IoT could help the firms in advancing the firms' sourcing activities. For example, the firms could use the electric nose to accept or reject the incoming raw materials, such as coffee, tea, fish, and fruit, based on its quality and origins (Peres et al., 2007). In addition, the electric cattle ear tags could collect the data, such as a tag number, biometric identifiers, date of birth, and herd details (Shanahan et al., 2009). Some companies used it to determine the authentication information of Halal ingredients (Ahmad Tarmizi et al., 2020).

Make: The food manufacturers were able to use the QM IoT in several making process. For instance, the RFID could track the humidity, temperature, product handling, mold growing, biological contamination, acid corrosion, ammoniacal gases, ripening status, and other important data, such as kind of milk, manufacturer, batch, and batch qualification for the cheese manufacturers (Pérez-Aloe et al., 2007). Furthermore, biosensors attached on the production lines could detect the residual peroxide during the cleaning process (Moody et al., 2001).

Deliver: Controlling the quality of the food during the delivery was also another challenge. Some researchers examined the benefit of QM IoT during the delivery. For example, the Flexible Tag Datalogger (FTD) attached on the bottle of the wine could monitor the quality of the product during the transporting, storing, and vending. The environmental changes, such as temperature, humidity, and light, during logistics chain activities, could be captured (Mattoli et al., 2009). In addition, the perishable foods, such as deep-frozen goods, fish and meat, and vegetables, could be tracked in real-time. When the temperature increased, the sensors could captured the change as the perishable goods released heat and carbon dioxide (Jedermann et al., 2009).

Return: It was important to always keep the quality and safety of the food thighed. However, there might be a case that the crisis happened unexpectedly. QM IoT could help the firms immediately realized the issues and recalled the goods if needed (Kumar & Budin, 2006). For instance, the use of Dynamic Expiration Date on the food package could help the firms determine the location of the expired products and got them returned (Heising et al., 2017).

Plan: Planning could also impact the quality and safety of the products. For example, the amount and period to add the fertilizers, pesticides, or water could be automatically determined based on the weather forecast, yield projections, and probability maps for diseases and disasters (Wahabzada et al., 2016; Walter et al., 2017). In addition, the livestock could have a proper amount and time for feeding due to the sensing signals, sensors, or actuators that attached on them (Walter et al., 2017).

It could be seen that the benefits of the IoT in the quality management of the food related supply chain was obviously dominant. However, it was shown that the IoT adoption rate was still in planning and proof-of-concept stage (Bosche et al., 2016) and still not fully exploit the collected data (Manyika et al., 2015). In Thailand, the Digital Economy Promotion Agency indicated that the adoption of IoT was still at the beginning stage (Digital Economy Promotion Agency, 2019), and the National Broadcasting and Telecommunication Commission has called an attention to fasten the adoption of IoT to maintain the competitive advantages for Thailand among other countries (National Broadcasting Telecommunications Commission, 2017). Therefore, the authors expected that the research results and the strategic recommendation provided could be useful for the IoT service providers in providing QM IoT services and could propel positive business impacts for the Thai industry.

Conceptual Framework

The authors defined the research conceptual framework as shown in Fig.1. There were three tools used in this research. First, the firm profiles that summarized from the surveys were analyzed and produced the strategic recommendation in selecting target customers. Secondly, the preference in using QM IoT in each SCOR area, including source, make, deliver, return, and plan, were collected and produced the recommendation on the areas of focus. Lastly, the details of activities under each SCOR area were scrutinized, and the lists of prioritized activities was produced accordingly.

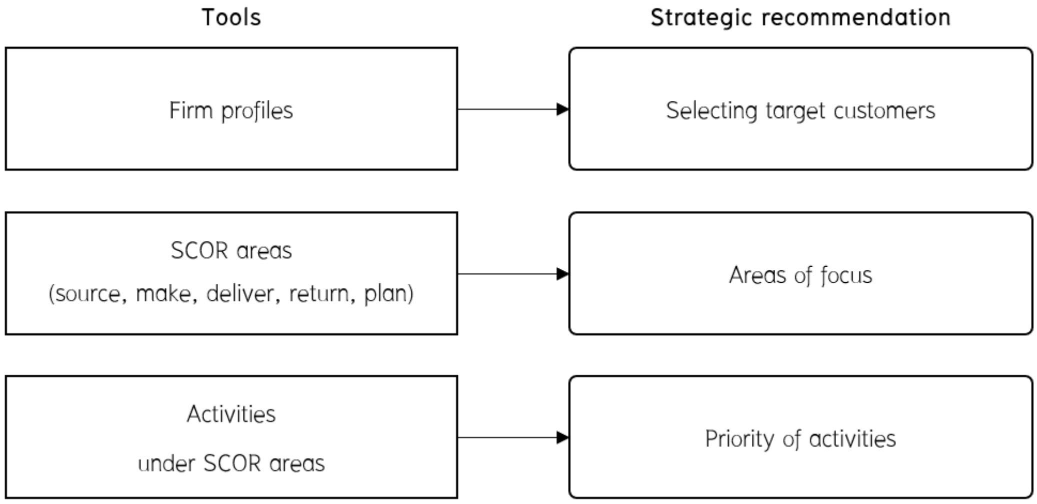

Fig.1 Conceptual Framework

Research Methodology

Population and sample: The target population in the research was the food processing manufacturers that registered with the Food Processing Industry Club, the federation of Thai industry (Food Processing Industry Club, 2021). The questionnaires were sent to 326 manufacturers, in which a supervisor, assistant manager, manager, or higher-level employees in supply chain, logistics, operations, production, quality, information technology, or related functions that worked closely with operations could be a representative to answer the questionnaires for his/her company. One firm could have only one representative to answer the questionnaires.

Research instruments: The questionnaires were constructed into 2 parts. First, the general questions included gender, age, education, current field of work, job level, total year of experience after graduated, company age, turnover per year, number of employees, company's category, firm nationality, availability of foreign shareholder(s), and availability of foreign management. The avoid duplicated answers from the same firm, the company name was asked but not reveled publicly. Secondly, the current and future usage of the QM IoT and areas of usage questionnaires that developed from the SCOR concepts were asked.

Data collection procedure: Once the questionnaires were developed from the literature review, they were tested by 5 experts, including in the supply chain, industrial engineering, quality, and information technology fields. Then, the amended questionnaires were filled in the Google Form and distributed to all 326 food processing manufacturers via emails. The researchers made three rounds of phone calls to ensure that emails were received and to remind them. The emails and phone numbers were received from the FOODFTI website.

Data analysis: The descriptive statistics, including average numbers and percentage were used to analyze the retrieved data. Then, the numbers were ranked up and compared to one another. The higher the average numbers and percentage in each area, the higher importance and interesting areas that the researchers would further summarize. After that, the authors provided the strategic recommendation for the IoT service providers in providing QM IoT services in three aspects, including selecting target customers, areas of focus (SCOR view), and priority of activity.

Research Results

Out of 326 population, 201 representatives of the food processing manufacturers registered with the Food Processing Industry Club, the Federation of Thai Industry responded the questionnaires. Four responses were dropped out due to incomplete answers, so 197 responses were further used to analyze.

Prior to the results of all objectives, the summary of answers from the general questions was summarized as follow. The respondents were female (58.4%), male (41.1%), and not specified (0.5%). The respondents' ages were between 35-45 years old (50.3%), 25-35 years old (42.6%), 45-55 years old (6.1%), and 55 years above (1.0%). Majority of the respondents held higher than bachelor's degree (56.9%), followed by bachelor's degree (43.1%). The current fields of work were logistics and supply chain (34.5%), quality (23.9%), production and operations (23.4%), commercial (7.1%), research and development (5.6%), general management (2.5%), performance (2.0%), and information technology (1.0%). The job level was ranked as managers (42.1%), supervisors (22.8%), assistant managers (16.2%), management or owners (9.7%), directors (5.1%), specialists (3.1%), and officers (1.0%). The total years of experience after graduated were 6-10 years (28.4%), 11-15 years (25.9%), 16-20 years (21.8%), 1-5 years (14.2%), and 20 years above (9.7%). The next three following sections, including 1. Firm profile, 2. SCOR areas, and 3. Activities under SCOR, were discussed. Then, the results were discussed and used to produced strategic recommendation accordingly.

1. Firm profile

The results showed that out of 197 firms, the 74 firms (37.6%) were currently using QM IoT, while 123 firms (62.4%) did not yet used it in their supply chain. However, 189 firms (95.9%)

expected to use QM IoT in the future, while 8 firms (4.1%) insisted that they would not use it in the future. The details of the firm profile, including company age, turnover per year, number of employees, firm nationality, foreign shareholder(s), and foreign management were shown as follow.

In total, the firm age ranged between less than 5 years (19 firms: 9.6%), 5–10 years (29 firms: 14.7%), 11–15 years (22 firms: 11.2%), and 15 years above (127 firms: 64.5%) as indicated in Table 1. Out of 74 firms that currently used QM IoT, 9 (4.6%), 12 (6.1%), 10 (5.1%), and 43 (21.8%) firms aged less than 5 years, 5–10 years, 11–15 years, and 15 years above, respectively. In the future, 189 firms potentially expected to use QM IoT, in which 19 (9.6%), 28 (14.2%), 20 (10.2%), and 122 (61.9%) firms aged less than 5 years, 5–10 years, 11–15 years, and 15 years above, respectively.

Table 1 Firm age

	Current				Future				Total	
	Use		No Use		Use		No Use			
Firm Age	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
Less than 5 Years	9	4.6%	10	5.1%	19	9.6%	–	0.0%	19	9.6%
5–10 Years	12	6.1%	17	8.6%	28	14.2%	1	0.5%	29	14.7%
11–15 Years	10	5.1%	12	6.1%	20	10.2%	2	1.0%	22	11.2%
15 Years above	43	21.8%	84	42.6%	122	61.9%	5	2.5%	127	64.5%
Total	74	37.6%	123	62.4%	189	95.9%	8	4.1%	197	100.0%

In addition, the turnover per year from the total 197 firms was listed as less than 100m THB (23 firms: 11.7%), 101–500m THB (32 firms: 16.2%), 501–1000m THB (36 firms: 18.3%), 1,001–5,000m THB (51 firms: 25.9%), 5,001–10,000m THB (22 firms: 11.2%), 10,001–50,000m THB (17 firms: 8.6%), 50,001–100,000m THB (5 firms: 2.5%), and 100,001m THB above (11 firms: 5.6%) as shown in Table 2. Out of 74 firms that currently used QM IoT, 7 (3.6%), 13 (6.6%), 11 (5.6%), 19 (9.6%), 7 (3.6%), 6 (3.0%), 4 (2.0%), and 7 (3.6%) firms had the turnover per year less than 100m THB, 101–500m THB, 501–1000m THB, 1,001–5,000m THB, 5,001–10,000m THB, 10,001–50,000m THB, 50,001–100,000m THB, and 100,001m THB above, respectively. In the future, 189 firms potentially expected to use QM IoT, in which 23 (11.7%), 29 (14.7%), 32 (16.2%), 51 (25.9%), 21 (10.7%), 17 (8.6%), 5 (2.5%), and 11 (5.6%) had the turnover per year less than 100m THB, 101–500m THB, 501–1000m THB, 1,001–5,000m THB, 5,001–10,000m THB, 10,001–50,000m THB, 50,001–100,000m THB, and 100,001m THB above, respectively.

Table 2 Turnover per year

	Current				Future				Total	
	Use		No Use		Use		No Use			
Turnover per Year	**Quantity**	**Percentage**	**Quantity**	**Percentage**	**Quantity**	**Percentage**	**Quantity**	**Percentage**	**Quantity**	**Percentage**
Less than 100m THB	7	3.6%	16	8.1%	23	11.7%	–	0.0%	**23**	**11.7%**
101 – 500m THB	13	6.6%	19	9.6%	29	14.7%	3	1.5%	**32**	**16.2%**
501 – 1,000m THB	11	5.6%	25	12.7%	32	16.2%	4	2.0%	**36**	**18.3%**
1,001 – 5,000m THB	19	9.6%	32	16.2%	51	25.9%	–	0.0%	**51**	**25.9%**
5,001 – 10,000m THB	7	3.6%	15	7.6%	21	10.7%	1	0.5%	**22**	**11.2%**
10,001 – 50,000m THB	6	3.0%	11	5.6%	17	8.6%	–	0.0%	**17**	**8.6%**
50,001 – 100,000m THB	4	2.0%	1	0.5%	5	2.5%	–	0.0%	**5**	**2.5%**
100,001m THB above	7	3.6%	4	2.0%	11	5.6%	–	0.0%	**11**	**5.6%**
Total	74	37.6%	123	62.4%	189	95.9%	8	4.1%	**197**	**100.0%**

Furthermore, the number of employees from the total 197 firms were less than or equal to 50 (28 firms: 14.2%), 51–200 (30 firms: 15.2%), 201–1,000 (78 firms: 39.6%), 1,001–5,000 (35 firms: 17.8%), 5,001–10,000 (13 firms: 6.6%), and more than 10,001 (13 firms: 6.6%) people as indicated in Table 3. Out of 74 firms that currently used QM IoT, 7 (3.6%), 11 (5.6%), 27 (13.7%), 15 (7.6%), 7 (3.6%), and 7 (3.6%) had the number of employees less than or equal to 50, 51–200, 201–1,000, 1,001–5,000, 5,001–10,000, and more than 10,001 people, respectively. In the future, 189 firms potentially expected to use QM IoT, in which 28 (14.2%), 28 (14.2%), 74 (37.6%), 33 (16.8%), 13 (6.6%), and 13 (6.6%) had the number of employees less than or equal to 50, 51–200, 201–1,000, 1,001–5,000, 5,001–10,000, and more than 10,001 people, respectively.

Table 3 Number of employees

Number of Employees	Current Use Quantity	Current Use Percentage	Current No Use Quantity	Current No Use Percentage	Future Use Quantity	Future Use Percentage	Future No Use Quantity	Future No Use Percentage	Total Quantity	Total Percentage
≤ 50 employees	7	3.6%	21	10.7%	28	14.2%	–	0.0%	28	14.2%
51 – 200 employees	11	5.6%	19	9.6%	28	14.2%	2	1.0%	30	15.2%
201 – 1000 employees	27	13.7%	51	25.9%	74	37.6%	4	2.0%	78	39.6%
1,001 – 5,000 employees	15	7.6%	20	10.2%	33	16.8%	2	1.0%	35	17.8%
5,001 – 10,000 employees	7	3.6%	6	3.0%	13	6.6%	–	0.0%	13	6.6%
≥ 10,001 employees	7	3.6%	6	3.0%	13	6.6%	–	0.0%	13	6.6%
Total	74	37.6%	123	62.4%	189	95.9%	8	4.1%	197	100.0%

The firm nationality from the total 197 firms included 112 (56.9%) firms from Thailand, 31 (15.7%) firms from USA, 14 (7.1%) firms from Japan, and 40 (20.3%) firms from the rest of the world as shown in Table 4. Currently, the top three firms that used QM IoT included 42 (21.3%), 13 (6.6%), and 4 (2.0%) from Thailand, USA, and Japan, respectively, while the rest 15 (7.6%) firms scattered from several countries. In the future, the top three firms expected to use QM IoT remained in the same ranks as from Thailand (107 firms: 54.3%), USA (30 firms: 15.2%), and Japan (14 firms: 7.1%), whereas the rest 38 (19.3%) firms were from several countries.

Table 4 Firm nationality

	Current				Future				Total	
	Use		No Use		Use		No Use			
Firm Nationality	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
Brazil	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
China	1	0.5%	1	0.5%	1	0.5%	1	0.5%	2	1.0%
England	2	1.0%	4	2.0%	6	3.0%	–	0.0%	6	3.0%
France	3	1.5%	3	1.5%	6	3.0%	–	0.0%	6	3.0%
Germany	–	0.0%	2	1.0%	2	1.0%	–	0.0%	2	1.0%
Ireland	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Japan	4	2.0%	10	5.1%	14	7.1%	–	0.0%	14	7.1%
Korea	1	0.5%	–	0.0%	1	0.5%	–	0.0%	1	0.5%
Malaysia	–	0.0%	2	1.0%	2	1.0%	–	0.0%	2	1.0%
Netherlands	1	0.5%	2	1.0%	2	1.0%	1	0.5%	3	1.5%
New Zealand	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Peru	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Philippines	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Singapore	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Spain	1	0.5%	–	0.0%	1	0.5%	–	0.0%	1	0.5%
Sweden	1	0.5%	–	0.0%	1	0.5%	–	0.0%	1	0.5%
Switzerland	2	1.0%	5	2.5%	7	3.6%	–	0.0%	7	3.6%
Thailand	42	21.3%	70	35.5%	107	54.3%	5	2.5%	112	56.9%
USA	13	6.6%	18	9.1%	30	15.2%	1	0.5%	31	15.7%
Total	74	37.6%	123	62.4%	189	95.9%	8	4.1%	197	100.0%

The foreign shareholders from the total 197 firms included 117 (59.4%) firms from Thailand, 21 (10.7%) firms from USA, 16 (8.1%) firms from Japan, and 43 (21.8%) firms from the rest of the world as shown in Table 5. Currently, the top three firms that used QM IoT, including 45 (22.8%), 8 (4.1%), and 5 (2.5%) had shareholders from Thailand, USA, and Japan, respectively, while the rest 16 (8.1%) firms' shareholders were from several countries. In the future, the shareholders from the top three firms expected to use QM IoT remained in the same ranks as from Thailand (111 firms: 56.3%), USA (21 firms: 10.7%), and Japan (16 firms: 8.1%), whereas the rest 41 (20.8%) firms indicated foreign shareholders from several countries.

Lastly, the foreign management from the total 197 firms included 116 (58.9%) firms from Thailand, 16 (8.1%) firms from Japan, 15 (7.6%) firms from USA, and 50 (25.4%) firms' management from the rest of the world as shown in Table 6. Currently, the top three firms that used QM IoT, including 43 (21.8%), 7 (3.6%), and 5 (2.5%) had management from Thailand, USA, and Japan, respectively, while the rest 19 (9.6%) firms' management were from other parts of the world. In the future, the shareholders from the top three firms expected to use QM IoT changed to from Thailand (109 firms: 55.3%), Japan (16 firms: 8.1%), and USA (15 firms: 7.6%), respectively, whereas the rest 49 (24.9%) firms indicated foreign management from several countries.

Table 5 Foreign shareholders

	Current				Future				Total	
	Use		No Use		Use		No Use			
Foreign Shareholder(s)	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
Belgium	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Brazil	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
China	2	1.0%	3	1.5%	4	2.0%	1	0.5%	5	2.5%
England	4	2.0%	2	1.0%	6	3.0%	–	0.0%	6	3.0%
France	4	2.0%	2	1.0%	6	3.0%	–	0.0%	6	3.0%
Germany	–	0.0%	2	1.0%	2	1.0%	–	0.0%	2	1.0%
Ireland	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Japan	5	2.5%	11	5.6%	16	8.1%	–	0.0%	16	8.1%
Malaysia	–	0.0%	2	1.0%	2	1.0%	–	0.0%	2	1.0%
Netherlands	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
New Zealand	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Philippines	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Singapore	–	0.0%	3	1.5%	2	1.0%	1	0.5%	3	1.5%
Spain	1	0.5%	–	0.0%	1	0.5%	–	0.0%	1	0.5%
Switzerland	1	0.5%	3	1.5%	4	2.0%	–	0.0%	4	2.0%
Thailand	45	22.8%	72	36.5%	111	56.3%	6	3.0%	117	59.4%
USA	8	4.1%	13	6.6%	21	10.7%	–	0.0%	21	10.7%
Unknown (International)	1	0.5%	4	2.0%	5	2.5%	–	0.0%	5	2.5%
Total	74	37.6%	123	62.4%	189	95.9%	8	4.1%	197	100.0%

Table 6 Foreign management

	Current				Future				Total	
	Use		No Use		Use		No Use			
Foreign Management	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
Australia	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Belgium	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Brazil	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
China	–	0.0%	1	0.5%	–	0.0%	1	0.5%	1	0.5%
England	3	1.5%	3	1.5%	6	3.0%	–	0.0%	6	3.0%
France	4	2.0%	2	1.0%	6	3.0%	–	0.0%	6	3.0%
Germany	–	0.0%	2	1.0%	2	1.0%	–	0.0%	2	1.0%
India	–	0.0%	4	2.0%	4	2.0%	–	0.0%	4	2.0%
Ireland	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Japan	5	2.5%	11	5.6%	16	8.1%	–	0.0%	16	8.1%
Korea	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Malaysia	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
New Zealand	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Peru	–	0.0%	1	0.5%	1	0.5%	–	0.0%	1	0.5%
Philippines	1	0.5%	1	0.5%	2	1.0%	–	0.0%	2	1.0%
Singapore	2	1.0%	3	1.5%	5	2.5%	–	0.0%	5	2.5%
Spain	1	0.5%	–	0.0%	1	0.5%	–	0.0%	1	0.5%
Switzerland	1	0.5%	–	0.0%	1	0.5%	–	0.0%	1	0.5%
Thailand	43	21.8%	73	37.1%	109	55.3%	7	3.6%	116	58.9%
USA	7	3.6%	8	4.1%	15	7.6%	–	0.0%	15	7.6%
Unknown (International)	1	0.5%	3	1.5%	4	2.0%	–	0.0%	4	2.0%
≥ 2 countries	4	2.0%	4	2.0%	8	4.1%	–	0.0%	8	4.1%
Total	74	37.6%	123	62.4%	189	95.9%	8	4.1%	197	100.0%

2. SCOR areas

The SCOR areas from 74 firms that currently used QM IoT on average were for source (30 firms: 15.2%), make (27 firms: 13.7%), deliver (25 firms: 12.7%), return (17 firms: 8.6%), and plan (19 firms: 9.6%). In the future, the focused areas from 187 firms that expected to use QM IoT indicated their interests in using it for source (94 firms: 47.7%), make (93 firms: 47.2%), deliver (89 firms: 45.2%), return (65 firms: 33.0%), and plan (73 firms: 37.1%). The details were shown in Fig. 2.

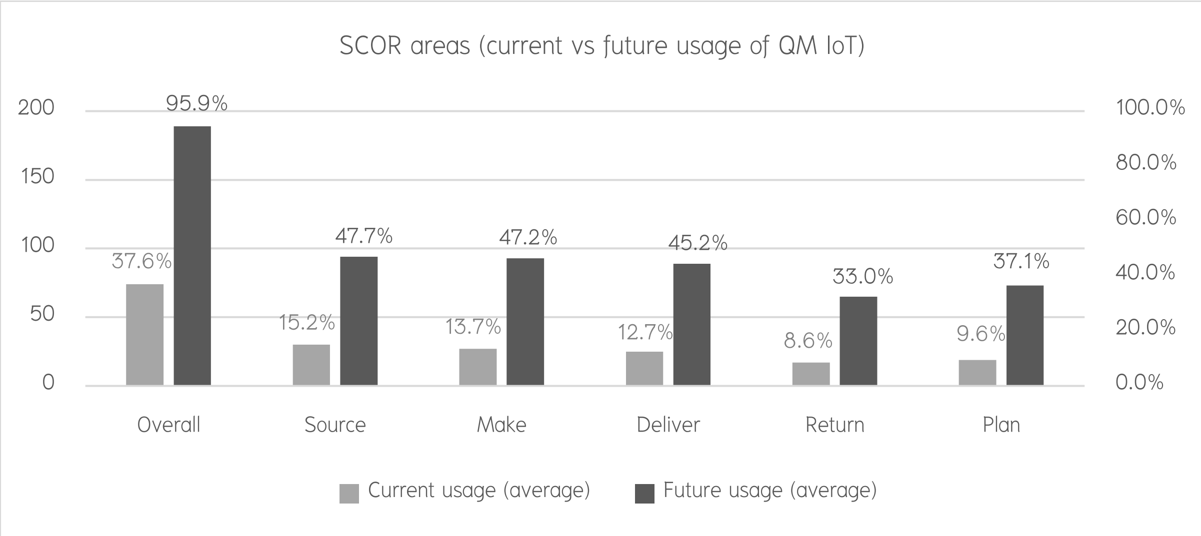

Fig 2. Current vs Future Usage of QM IoT (SCOR View)

3. Activities under SCOR

The detailed activities under each SCOR area, including source, make, deliver, return and plan were explained in each section thereafter.

Source: Currently, the firms had used QM IoT mainly for transferring and storing sourcing materials (35 firms: 17.8%), followed by receiving, verifying, and identifying sourcing materials (31 firms: 15.7%), and selecting and negotiating with suppliers (24 firms: 12.2%). In the future, the firms shifted the priority to receiving, verifying, and identifying sourcing materials (122 firms: 61.9%). Then, it followed by transferring and storing sourcing materials (99 firms: 50.3%) and selecting and negotiating with suppliers (62 firms: 31.5%). The summary and comparison for the current and future usage for source by activities was shown in Fig 3.

Make: Currently, the firm focused on the activities, including monitoring production, staging, and packaging process (38 firms: 19.3%), releasing materials and products (32 firms: 16.2%), testing the products (25 firms: 12.7%), and disposing waste (13 firms: 6.6%). In the future, the firms were interested in using QM IoT in releasing materials and products (118 firms: 59.9%), monitoring production, staging, and packaging process (106 firms: 53.8%), testing the products (101 firms: 51.3%), and disposing waste (47 firms: 23.9%). The summary and comparison for the current and future usage for make by activities was shown in Fig 4.

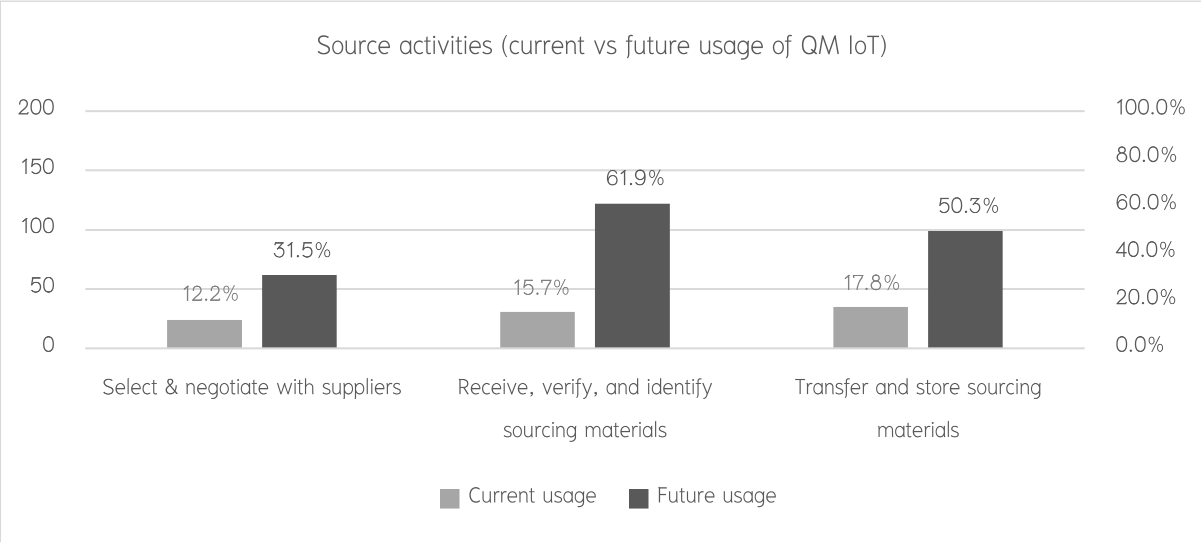

Fig 3. Source activities (current vs future usage of QM IoT)

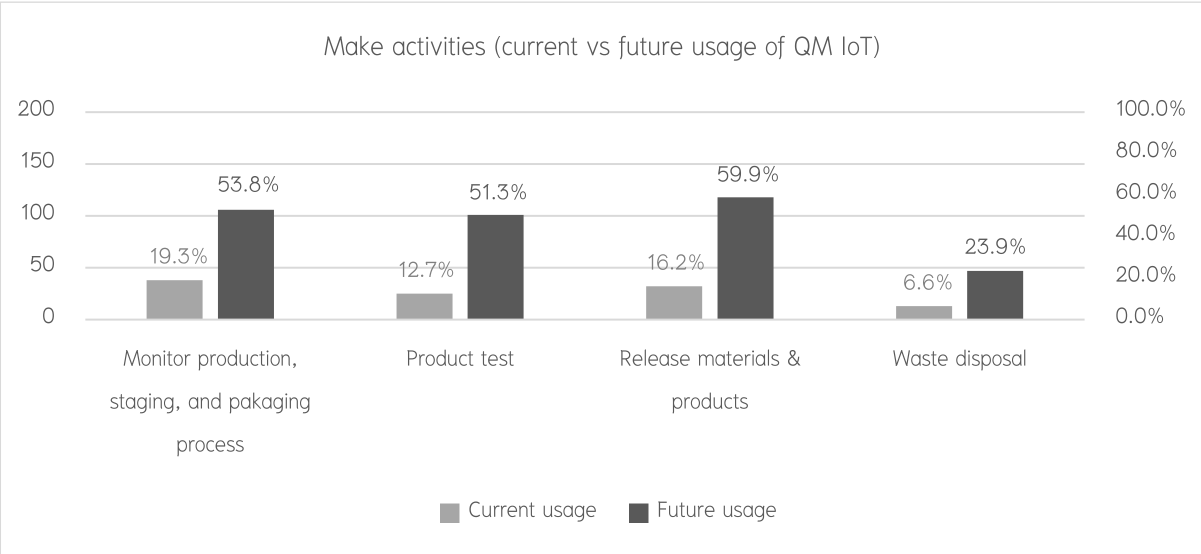

Fig 4. Make activities (current vs future usage of QM IoT)

Deliver: Currently, the firms mostly used it to receive, enter, validate, and consolidate orders (36 firms: 18.3%), followed by receiving products form source or make (23 firms: 11.7%), routing and rating shipment and selecting carriers (21 firms: 10.7%), and storing and reserving inventory, picking, packing, and building loads (18 firms: 9.1%). In the future, the firms expected to use it for receiving, entering, validating, and consolidating orders (101 firms: 51.3%), receiving products form source or make (96 firms: 48.7%), storing and reserving inventory, picking, packing, and building loads (84 firms: 42.6%), and routing and rating shipment and selecting carriers (74 firms: 37.6%). The summary and comparison for the current and future usage for deliver by activities was shown in Fig 5.

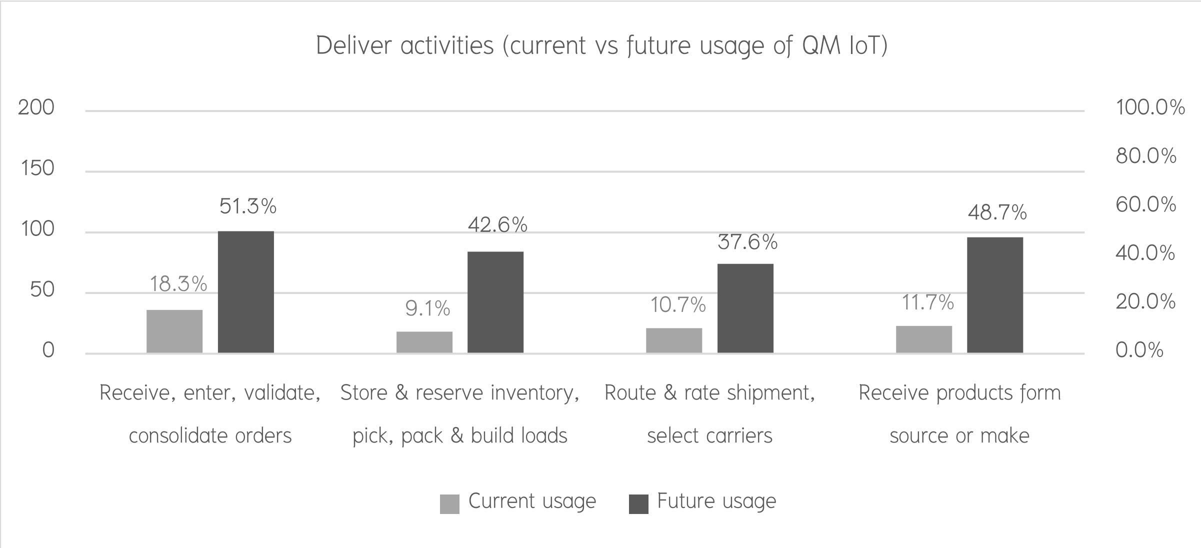

Fig 5. Deliver activities (current vs future usage of QM IoT)

Return: Currently, the firms use it for identifying defects, maintenance, repairs, and operations (MRO), and excessing products from the suppliers (17 firms: 8.6%) and customers (17 firms: 8.6%), while they also used it for requesting, returning, and transferring defects, MRO, and excess products to suppliers (16 firms: 8.1%) and form customers (17 firms: 8.6%). In the future, they prioritized to use it for requesting, returning, and transferring defects, MRO, and excess products to suppliers (71 firms: 36.0%) and form customers (71 firms: 36.0%). The firms planned to use it for identifying defects, MRO, and excessing products from the customers (62 firms: 31.5%) and suppliers (55 firms: 27.9%). The summary and comparison for the current and future usage for deliver by activities was shown in Fig 6.

Plan: Currently, they used it to identify, prioritize, access the sourcing product (23 firms: 11.7%), delivery (16 firms: 8.1%), production (15 firms: 7.6%), and return (14 firms: 7.1%) requirement and resources. They also used it for establishing and scheduling the production plan (26 firms: 13.2%), delivery plan (25 firms: 12.7%), sourcing plan (22 firms: 11.2%), and returning

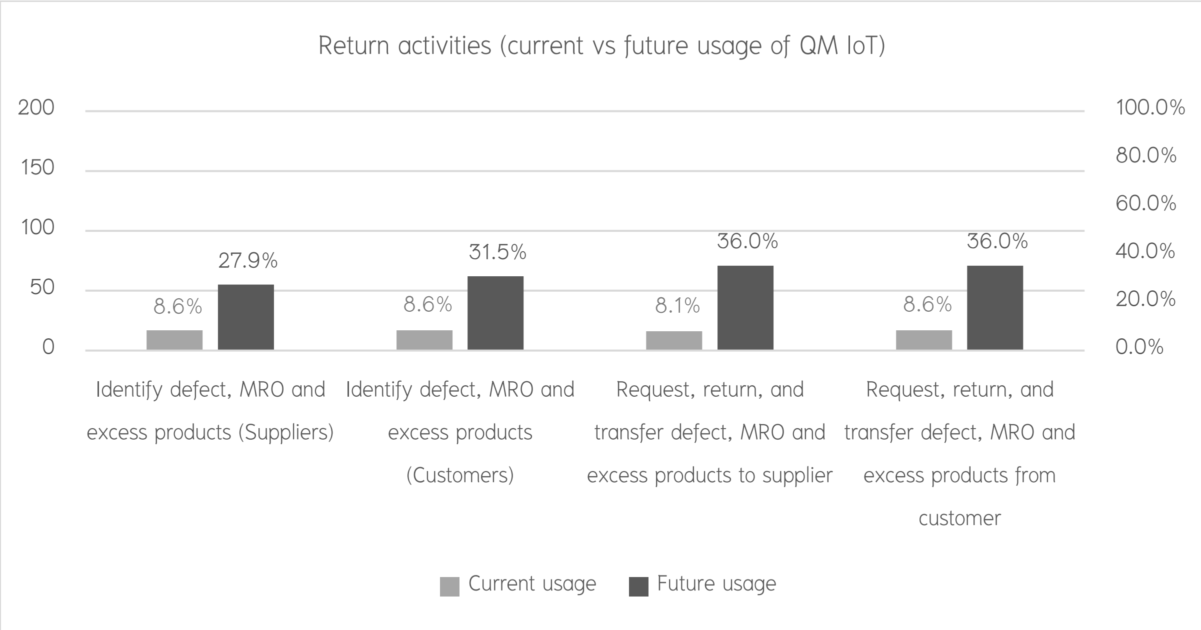

Fig 6. Return activities (current vs future usage of QM IoT)

plan (13 firms: 6.6%). In the future, they planned to use it for identifying, prioritizing, accessing the sourcing product (83 firms: 42.1%), delivery (79 firms: 40.1%), production (60 firms: 30.5%), and return (58 firms: 29.4%) requirement and resources. Then, they planned to use it for establishing and scheduling the delivery plan (90 firms: 45.7%), sourcing plan (79 firms: 40.1%), production plan (77 firms: 39.1%) and returning plan (60 firms: 30.5%). The summary and comparison for the current and future usage for plan by activities was shown in Fig 7.

Discussion & Strategic Recommendations

The objective was to provide the strategic recommendation for the IoT service providers in providing QM IoT services. The authors categorized the recommendation into three aspects, including selecting target customers, areas of focus (SCOR view), and priority of activities. Each of these was discussed and recommended respectively.

1. Selecting target customers

The results obviously showed that the manufacturers were interested in using QM IoT within their firms as the usage percentages went up from 37.6% (74 firms) to 95.9% (189 firms). The result was quite meaningful since almost all the food manufacturers were tentatively interested and expected to use it in the future. However, the sales could be fostered if the IoT service providers could approach the main or the right groups of customers as recommended thereafter.

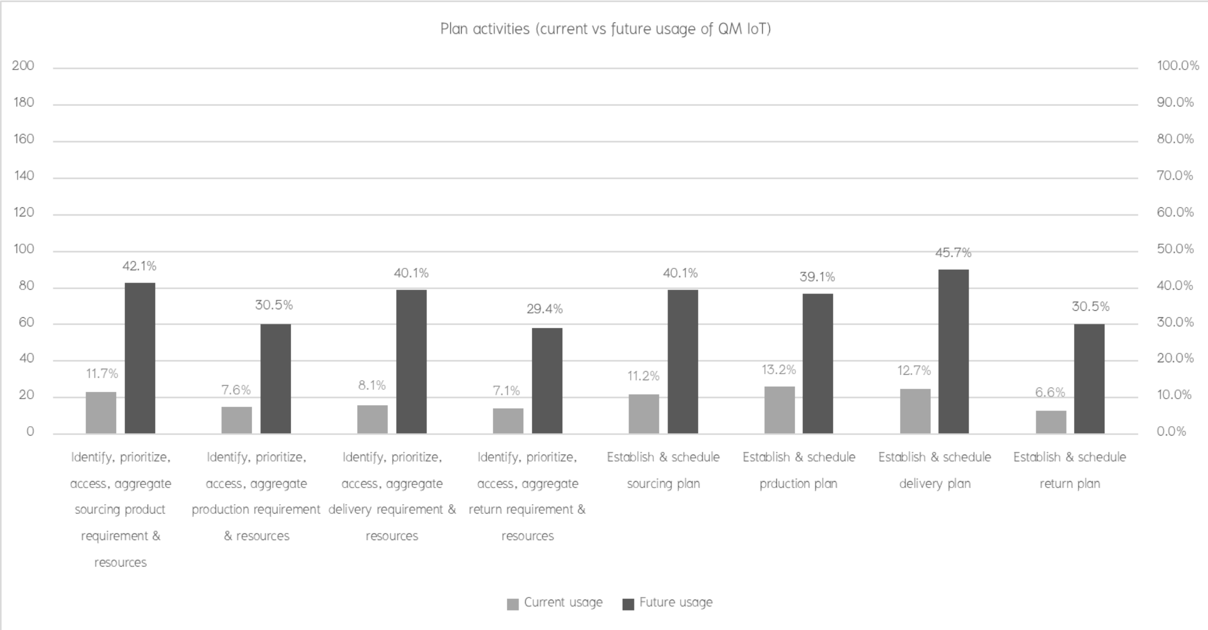

Fig 7. Plan activities (current vs future usage of QM IoT)

In term of company age, the IoT service providers could approach the firms aged less than 5 years first since 100% of them expected to use QM IoT in the future. Then, they could continue with firms aged between 5-10 years, 15 years above, and 11-15 years as the second priority since some of them were still reluctant in adopting QM IoT. In addition, the IoT service providers could apply the same logic and prioritize the firms that had turnover less than 100m THB, 1,001-5,000m THB, 10,001–50,000m THB, 50,001– 100,000m THB, and 100,001 m THB above as all the firms in these ranges expected to use QM IoT in the future, respectively. Then, the firms could later approach the firms with the turnover between 5,001–10,000m THB, 101-500m THB, and 501–1,000m THB as they indicated lower positive chance to buy the products or services, respectively. Furthermore, the IoT service providers could prioritize in giving services to the firms with employees less than or equal to 50, 5,001–10,000, and 10,001 employees above because all of them did not refuse to adopt the QM IoT. Then, they could continue with the firms with the number of employees between 201-100, 1,001–5,000 employees, and 51–200 employees as the second priority, respectively. Thus, the higher the criteria these potential customers had, the higher chance that the IoT service providers could make the deals.

Apart from the company age, turnover per year, and the number of employees, the IoT service providers could consider the firm nationality, foreign shareholders, and foreign management. For the firm nationality, the firms could prioritize on the firms' nationalities that gave 100% positive feedback to the survey, including from Brazil, England, France, Germany, Ireland, Japan, Korea, Malaysia, New Zealand, Peru, Philippines, Singapore, Spain, Sweden, Switzerland. Even though the number of firms that carried these nationalities was not high, the change to make sales are maximum. Then, the IoT service providers could approach the firm from USA and Thailand as the second priority, respectively. They should focus less on the firms from Netherland and China due to the lower chance for sales. In addition, the firms with the foreign shareholders, including from Belgium, Brazil, England, France, Germany, Ireland, Japan, Malaysia, Netherlands, New Zealand, Philippines, Spain, Switzerland, USA should be the first priority in approaching for sales as they indicate 100% positive signs to adopt the QM IoT. Then, the firms with no foreign shareholders (Thai) could be the second priority, whereas the China and Singapore reported to be the last priority due to their least preference in using QM IoT. Furthermore, the firms with the foreign management, including from Australia, Belgium, Brazil, England, France, Germany, India, Ireland, Japan, Korea, Malaysia, New Zealand, Peru, Philippines, Singapore, Spain, Switzerland, and USA because they indicated only positive signs in using QM IoT. Then, the second priority could be given to the firm with Thai management. The least priority fell into the firms with the management from China.

Once the target customers were selected, the IoT service providers should understand the areas of focus on the services provided, in which were recommended in the next section.

2. Areas of focus (SCOR view)

Even though the food manufacturers indicated higher interests in using QM IoT currently from 74 (37.6%) firms to 189 (95.9%) firms in the future, the percentage of interests in each SCOR area in the future did not even exceed 50%. However, the areas that the IoT service providers had better focus should be ranked from source (47.7%), make (47.2%), deliver (45.2%), plan (37.1%), and return (33.0%). The ranks actually remained the same as the current QM IoT usage areas but indicated with the higher percentage. Similarly, the results in another research in industrial 4.0 from the German manufacturers also indicated that their existing usage of Industry 4.0 solutions based on SCOR perspectives did not exceed 50% in each area in 2019 (Müller, 2019).

In this research, the results were also quite interesting for the highest one (source: 47.7%) since the authors expected that make area (47.2%) had better be the highest one due to the survey that responded by the manufacturers. Thus, it was indicated that the firm prioritized a lot on the quality of the incoming raw materials, and the source area became the highest interest in using QM IoT from the food manufacturers. The authors then recommended the IoT service providers to prioritize on the top 3 areas, including source, make, and deliver as their percentages of interests in using QM IoT similarly clustered the highest between 45.2%-47.7%. Thus, plan and return areas should then be the second priority. However, the German manufacturers indicated the top three priority as source, make, and plan based on the average current usage of industrial 4.0 solutions in 2019 (Müller, 2019). The detail activities for the top 3 areas were discussed in the next section accordingly.

3. Priority of Activities

Source (47.7%) was the highest SCOR area that the firms expected to use it the future. It might be because of incoming raw materials required high quality controls during reception. Thus, the materials with lower than the specification or standard would be automatically reported or alarmed. Currently, the firms used it for all 3 activities on a very similar level, including transferring and storing sourcing materials (17.8%), receiving, verifying, and identifying the sourcing materials (15.7%), and selecting and negotiating with suppliers (12.2%). However, they mostly expected sourcing activities to use included receiving, verifying, and identifying the sourcing materials (61.9%) and for transferring and storing sourcing materials (50.3%). These 2 sourcing activities was meant to facilitate the ways they operated and handled the incoming materials/products at their warehouses or factories. Thus, the IoT service providers should highly pay attention one these 2 activities. The respondents focused less on the activities to select and negotiate with suppliers (31.5%), so the providers should put less priority on this activity.

The second highest SCOR area that firms were interested in was for making (47.2%). Though make was the second chosen area, the average usage percentage in the future only less than sourcing by 0.5% at 47.2%. Thus, it should also be one of the focusing areas as the good quality incoming raw materials might be transformed into bad ones if the quality control processes during production were not properly implemented. Currently, three of the four activities under the making area indicated the most usage included monitoring production, staging, and packing process (19.3%), releasing materials and products (16.2%), and product test (12.7%). These three activities still maintained the focus from these firms which expected to use QM IoT for in the future. The percentage increased to between 51.3%–59.9% for these 3 activities. Thus, high attention on these 3 activities was required from the IoT service providers. However, waste disposal activity was still not be the focus as it had lowest percentage from current at 6.6% to the future at 23.9%. Therefore, less focus should be paid for this activity.

The third highest SCOR area was for delivering (45.2%). The manufacturers still needed to use QM IoT during the delivery of their good products manufactured. No matter current or future usage, the solely delivering activity that the firms highlighted the most was to receive, enter, validate, and consolidate orders with the current percentage at 18.3% and future percentage at 51.3%. Therefore, the IoT service providers should also focus on better offering this service. The rest three activities did not even exceed 50% interest in using QM IoT in the future from these firms, while the current usage of those also indicated tentatively low percentage between 9.1%-11.7%. Therefore, second priority was given to these activities, including receiving products form source or make (48.7%), storing and reserving inventory, picking, packing, and building loads (42.6%), and routing and rating the shipment and selecting carriers (37.6%).

One of the two SCOR activities that got the lowest interest from the food manufacturers were plan (37.1%) and followed by return (33.0%). These 2 SCOR areas were currently ranked as the lowest interest at 9.6% and 8.6%, respectively; they were also continued to be ranked as the lowest ones for the future usage at 37.1% and 33.0%. However, it would be more meaningful to investigate the highest interest per area for the IoT service providers for later service in the future. First, the highest percentage activity for the planning area was to establish and schedule delivery plan (45.7%). Secondly, the highest percentage for the return activity was to request, return, and transfer defect, MRO, and excess products to suppliers (36.0%) and from customers (36%). The rest of the activities under plan and return areas could be considered as less priority.

All five areas of SCOR view, including source, make, deliver, return, and plan, were important to efficient supply chain management. However, source, make, and deliver were the top priority for the IoT service providers as they indicated future interests at 45.2-47.7% based on these group of respondents in this research. In another research of German manufacturers, the importance of source and make remained the first two priority, but the plan replaced as their third priority instead of deliver area (Müller, 2019). The differences in the results might cause from the variation in industries, countries, and period in conducting research.

Knowledge from Research

The outcome of the research indicated that the food processing manufacturers expected to use QM IoT more in the future. The types of firms that the IoT service providers should firstly approach were addressed. The SCOR areas that the firms expected to use were investigated and prioritized. Also, the activities under each SCOR area were intensively discussed and ranked up its importance. Therefore, the IoT service providers could apply the strategic recommendation to formulate their strategic management to foster more business opportunities.

The strategic recommendation, including selecting target customers, areas of focus, and priority of activities, were summarized in Fig. 8.

Tools	Strategic recommendation
Firm profiles	**Selecting target customers** • Firms aged less than 5 years • Firm with turnover less than 100m THB, 1,001–5,000m THB, 10,001–50,000m THB, 50,001– 100,000m THB, 100,001 m THB above • Firms with employees less than or equal to 50, 5,001–10,000, 10,001 employees above • Firms' nationalities from: Brazil, England, France, Germany, Ireland, Japan, Korea, Malaysia, New Zealand, Peru, Philippines, Singapore, Spain, Sweden, Switzerland. • Foreign shareholders from: Belgium, Brazil, England, France, Germany, Ireland, Japan, Malaysia, Netherlands, New Zealand, Philippines, Spain, Switzerland, USA • Foreign management from: Australia, Belgium, Brazil, England, France, Germany, India, Ireland, Japan, Korea, Malaysia, New Zealand, Peru, Philippines, Singapore, Spain, Switzerland, USA
SCOR areas	**Areas of focus** • source (47.7%), make (47.2%), deliver (45.2%)
Activities under SCOR areas	**Priority of activities** • Receiving, verifying, and identifying sourcing materials (122 firms: 61.9%) • Transferring and storing sourcing materials (99 firms: 50.3%) • Releasing materials and products (118 firms: 59.9%) • Monitoring production, staging, and packaging process (106 firms: 53.8%) • Testing the products (101 firms: 51.3%) • Receiving, entering, validating, and consolidating orders (101 firms: 51.3%).

Fig 8. Finding diagram

First, the firm profiles were analyzed, and the target customers for the IoT service providers to firstly approach were the firms aged less than 5 years, with turnover less than 100m THB, 1,001–5,000m THB, 10,001–50,000m THB, 50,001– 100,000m THB, and 100,001 m THB above, and with employees less than or equal to 50, 5,001–10,000, and 10,001 employees above, with nationalities from Brazil, England, France, Germany, Ireland, Japan, Korea, Malaysia, New Zealand, Peru, Philippines, Singapore, Spain, Sweden, Switzerland, with foreign shareholders from Belgium, Brazil, England, France, Germany, Ireland, Japan, Malaysia, Netherlands, New Zealand, Philippines, Spain, Switzerland, USA, and with foreign management from Australia, Belgium, Brazil, England, France, Germany, India, Ireland, Japan, Korea, Malaysia, New Zealand, Peru, Philippines, Singapore, Spain, Switzerland, and USA. The firms that categorized in the mentioned criteria indicated relatively positive responses in using QM IoT in the future. Secondly, the areas of focus were source (47.7%), make (47.2%), and deliver (45.2%) as they indicated the highest interests from the firms in using QM IoT for. Thirdly, the priority of activities that received more than 50% of interests included receiving, verifying, and identifying sourcing materials (122 firms: 61.9%), transferring and storing sourcing materials (99 firms: 50.3%), releasing materials and products (118 firms: 59.9%), monitoring production, staging, and packaging process (106 firms: 53.8%), testing the products (101 firms: 51.3%), and receiving, entering, validating, and consolidating orders (101 firms: 51.3%).

Conclusion

The food has travel in longer distances from upstream suppliers to downstream customers, like us. The concern was on how we could ensure that the food we consumed was in good quality and safety conditions. With the introduction of the Internet of things (IoT), the manufactures could improve their quality management along the processes in the supply chain. The Thai government also raised concerns on the slow adoption of IoT in Thailand to remain the competitiveness. Instead of focusing on the IoT adoption factors for the manufacturers, the authors focused on providing the strategic recommendation for the IoT service providers. The data from collected from 197 food processing manufacturers registered with the Food Processing Industry Club, the Federation of Thai Industry were analyzed. The objective as to provide the strategic recommendation for the IoT service providers in providing QM IoT services was provided accordingly.

It was shown that the firm increased their interests in using QM IoT currently from 37.6% to 95.9% in the future. The strategic recommendation was categorized into three parts. First, the target customers were recommended based on the firm age, turnover per year, number of employees, nationalities, foreign shareholders, and foreign management that indicated 100% interests in using QM IoT in the future. Second, the SCOR areas that the service providers should focus consisted of source, make, and deliver as clustered together among top three areas. Third, 2 activities from source, 3 activities from make, and 1 activity from deliver were recommended to prioritize as these activities indicated more than 50% of interests from the food manufacturers.

The IoT service providers could use the results from the research objective that properly examined to expand their business. Not only the IoT service providers but also the food manufacturers could gain benefits from the adoption of QM IoT. In addition, the government could also potentially reduce the adoption gaps of IoT in the Thai market, and Thai market could receive positive economic impacts accordingly.

Suggestions

The respondents in the research were limited to the food processing manufacturers that registered with the Thai government. In the future, the researchers can investigate the adoption of QM IoT for other services, such as in healthcare or hospital services. These areas are also quite important since the quality and safety needs to be in place to ensure that the patients can receive the most accurate diagnosis. Thus, the introduction of QM IoT could help the healthcare or hospital services to ensure its quality management process. In addition, the researchers could select a QM IoT service provider and investigate the performance after applying the strategic recommendation retrieved from this research.

References

Ahmad Tarmizi, H., Kamarulzaman, N. H., Abd Rahman, A., & Atan, R. (2020). Adoption of internet of things among Malaysian halal agro-food SMEs and its challenges. *Food Research*, *4*(1), 256–265. https://doi.org/10.26656/fr.2017.4(S1).S26

Al-Rub, F. A., Shibhab, P., & Al-Rub, S. A. (2020). *Quality Management Systems (ISO 9001: 2015)*. GAVIN eBooks. https://doi.org/10.29011/978-1-951814-01-4-002

Bosche, A., Crawford, D., Jackson, D., Schallehn, M., & Smith, P. (2016). How Providers Can Succeed in the Internet of Things. *Bain & Company*, *29*.

Carcary, M., Maccani, G., Doherty, E., & Conway, G. (2018, September). Exploring the determinants of IoT adoption: Findings from a systematic literature review. In *International Conference on Business Informatics Research* (pp. 113–125). Springer, Cham.

Codex Alimentarius Commission. (2022). *About Codex Alimentarius*. Codex Alimentarius Commission. http://www.fao.org/fao-who-codexalimentarius/en/

Digital Economy Promotion Agency. (2019). *Thailand Digital Technology Foresight*. Frost & Sullivan.

Dweekat, A. J., Hwang, G., & Park, J. (2017). A Supply Chain Performance Measurement Approach Using the Internet of Things: Toward more Practical SCPMS. *Industrial Management & Data Systems*, *117*(2), 267–286. https://doi.org/10.1108/IMDS-03-2016-0096

Food Processing Industry Club. (2021). *Club Member Lists*. The Federation of Thai Industry. https://www.foodfti.com

GS1. (2017). *GS1 Global Traceability Standard*. GS1 AISBL. https://www.gs1.org/sites/default /files/docs/traceability/GS1_Global_Traceability_Standard_i2.pdf

Heising, J. K., Claassen, G. D. H., & Dekker, M. (2017). Options for Reducing Food Waste by Quality-controlled Logistics using Intelligent Packaging Along the Supply Chain. *Food Additives & Contaminants: Part A*, *34*(10), 1672–1680.

Jedermann, R., Ruiz-garcia, L., & Lang, W. (2009). Spatial Temperature Profiling by Semi-passive RFID Loggers for Perishable Food Transportation. *Computers and Electronics in Agriculture*, *65*(2), 145–154. https://doi.org/10.1016/j.compag.2008.08.006

Kevin, A. (2009). That 'Internet of Things' Thing. *RFID Journal*, *22*(7), 97–114.

Khunboa, C. (2019). *Internet of Things*. SE-EDUCATION.

Kumar, S., & Budin, E. M. (2006). Prevention and Management of Product Recalls in the Processed Food Industry: A Case Study Based on an Exporter's Perspective. *Technovation*, *26*, 739–750. https://doi.org/10.1016/j.technovation.2005.05.006

Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., & Aharon, D. (2015). The Internet of Things: Mapping the Value beyond the Hype. *McKinsey Global Institute*, *1*.

Mattoli, V., Mazzolai, B., Mondini, A., Zampolli, S., & Dario, P. (2009). Flexible Tag Datalogger for Food Logistics. *Procedia Chemistry*, *1*(1), 1215–1218. https://doi.org/10.1016/j.proche.2009.07.303

Moody, A., Setford, S., & Saini, S. (2001). Peroxidase enzyme sensor for on-line monitoring of disinfection processes in the food industry. *Analyst*, *126*(10), 1733–1739. https://doi.org/10.1039/B103591F

Müller, J. M. (2019). Contributions of Industry 4.0 to quality management – A SCOR perspective. *IFAC-PapersOnLine*, *52*(13), 1236–1241.

National Broadcasting Telecommunications Commission (NBTC). (2017). *Internet of Things Technology and Thailand 4.0 Policy*. NBTC. https://www.nbtc.go.th/getattachment/Services/quarter2560/%E0%B8%9B%E0%B8%B5-2561/32279/%E0%B9%80%E0%B8%AD%E0%B8%81%E0%B8%AA%E0%B8%B2%E0%B8%A3%E0%B9%81%E0%B8%99%E0%B8%9A.pdf.aspx

Pang, Z., Chen, Q., Han, W., & Zheng, L. (2015). Value-centric Design of the Internet-of-things Solution for Food Supply Chain: Value Creation, Sensor Portfolio and Information Fusion. *Information Systems Frontiers*, *17*(2), 289-319. https://doi.org/10.1007/s10796-012-9374-9

Peres, B., Barlet, N., Loiseau, G., & Montet, D. (2007). Review of the Current Methods of Analytical Traceability Allowing Determination of the Origin of Foodstuffs. *Food Control*, *18*(3), 228-235. https://doi.org/10.1016/j.foodcont.2005.09.018

Pérez-Aloe, R., Valverde, J. M., Lara, A., Carrillo, J. M., Roa, I., & González, J. (2007, September). Application of RFID Tags for the Overall Traceability of Products in Cheese Industries. In *2007 1st Annual RFID Eurasia* (pp. 1-5). IEEE.

Shanahan, C., Kernan, B., Ayalew, G., McDonnell, K., Butler, F., & Ward, S. (2009). A Framework for Beef Traceability from Farm to Slaughter using Global Standards: An Irish Perspective. *Computers and Electronics in Agriculture*, *66*(1), 62-69. https://doi.org/10.1016/j.compag.2008.12.002

Sheng, Q. Z., Zeadally, S., Luo, Z., Chung, J. Y., & Maamar, Z. (2010). Ubiquitous RFID: Where are we?. *Information Systems Frontiers*, *12*(5), 485-490. https://doi.org/10.1007/s10796-009-9212-x

Wahabzada, M., Mahlein, A. K., Bauckhage, C., Steiner, U., Oerke, E. C., & Kersting, K. (2016). Plant Phenotyping using Probabilistic Topic Models: Uncovering the Hyperspectral Language of Plants. *Scientific Reports*, *6*(1), 1-11. https://doi.org/10.1038/srep22482

Walter, A., Finger, R., Huber, R., & Buchmann, N. (2017). Smart Farming is Key to Developing Sustainable Agriculture. In *Proceedings of the National Academy of Sciences of the United States of America*, *114*(24), 6148-6150. https://doi.org/10.1073/pnas.1707462114

Ying, F., & Fengquan, L. (2013, June). Application of Internet of Things to the Monitoring System for Food Quality Safety. In *2013 Fourth International Conference on Digital Manufacturing & Automation* (pp. 296-298). IEEE.