THE EVALUATION FOR SMEs OF COLD CHAIN AGRICULTURAL FOOD INDUSTRY 4.0 PERFORMANCE IN THAILAND

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Abstract

Thailand ranks as the eighth-largest exporter of agricultural foods globally, with exports valued at approximately USD 28.8 billion, yet small and medium enterprises (SMEs) in this sector face significant challenges in maintaining cold chain efficiency and reducing food loss and waste.

Purpose: This study investigates the structural relationships between digital transformation adaptation, smart management systems, Supply Chain 4.0 capabilities, and food loss and waste minimization amongst Thai agricultural food SMEs.

Design/methodology/approach: The Structural Equation Model (SEM) to test six hypotheses, utilizing confirmatory factor analysis to ensure construct validity and reliability.

Findings: The findings provide actionable insights for SME managers and policymakers, emphasizing the critical role of digital technologies in enhancing cold chain logistics performance that using survey data from 452 SMEs in Thailand's agricultural food industry.

Research limitations/implications (if applicable): The study focuses on SME of Agriculture food industry in Thailand limiting generalizability to other emerging economies or developed markets that strengthen the understanding of how relationships evolve over time.

Practical implications (if applicable): The implications extend beyond individual firm performance to broader societal benefits, including social reduced food waste, improved food security, and enhanced sustainability. As such, continued research and support for Cold Chain Logistics 4.0 implementation in emerging economies represents both an economic opportunity and a social imperative.

Originality/value: This study provides empirical evidence for the critical role of digital transformation and smart management systems in enhancing Cold Chain Logistics 4.0 performance among Thai agricultural food SMEs. The findings demonstrate that investments in digital technologies and management system innovations significantly enhance Supply Chain 4.0 capabilities and organizational capabilities, which in turn contribute to substantial reductions in food loss and waste.

Keywords: Cold Chain Logistics, Industry 4.0, Digital Transformation , Smart Management, Supply Chain

Introduction

According to Food and Agriculture Organization of the United Nations (2021), agricultural food is defined comprise all food products that originate from crop, livestock, and fishery that encompass the entire range of actors and their interlinked value adding activities in the primary production of food agricultural products, as well as in food storage, aggregation, post-harvest handing transportation, processing, distribution, marketing, disposal and consumption within agricultural food systems.

From Agriculture Global Market Report (2024), (Company, 2025).The global agriculture market size grew from $13,272.75 billion in 2023 to $14,356.23 billion in 2024 at compound annual growth rate (CAGR) of 9.4%. The Russia-Ukraine war disrupted the chance of global economic recovery from the COVID-19 pandemic, at least in the short term. The war between these two countries has led to economic sanctions on multiple countries, a surge in commodity prices, and supply chain disruptions, causing inflation across goods and service and affecting many markets across the globe. The market size of global agriculture market is expected to grow to $19,286.79 billion in 2028 at a CAGR of 7.7 %.

The outbreak of COVID-19 disease has acted as a massive restraint on the agriculture market in 2020 as supply chains were disrupted due to trade restricts and consumption declined due to lockdowns imposed by governments globally. However, it is expected that the agriculture market will recover from the shock over the forecast period as it is a “black swan” event and related to ongoing or fundamental weaknesses in the market or the global economy. A shortage of labour and increasing demand for advanced agriculture tools in many countries is driving the demand for agriculture robots, or agri-robots. For instance, agri-robots are used on farmlands for pruning, weeding, and spraying pesticides and herbicides. The informations from Agriculture Global Market Report (2024) (Company, 2025) that illustrates agriculture food businesses have to supported by technologies.

In 2011, German scholars coined Industry 4.0 to highlight the start of fourth industrial revolution at the Hannover fair. In 2023, industry trend (Włodarczyk, 2023) the next step in industry 4.0 will be AI recommendation systems in production, new approach to robotics, virtualization of hardware, digital twins, manufacturing X, focus on cognitive ergonomics, open source and data rooms with connected platform. The adoption of industry 4.0 is a global approach that involves digitizing some of manufacturing, retailing, warehousing, transportation, retailing, warehousing, transportation, and industrial procedures of the logistics industry by providing transparency and traceability of goods along the supply chain (Shaiful Fitri Abdul Rahman et al., 2022)The transition of logistics processes towards Logistics 4.0, the specific application of Industry 4.0 in the logistics systems contributes to the combination of Internet Things (IoT), big data, cloud computing, and artificial intelligence allows improvements and optimisation in many logistics processes for advanced stable real-time communication (Lagorio et al., 2023) Agriculture Global Market Report (2024 (Company, 2025)The market size of global agriculture market is expected to grow to $19,286.79 billion in 2028 at a CAGR of 7.7 %. Hence, Cold chain logistics is the technology and process that allow for safe transportation of temperature sensitive goods and products along the supply chain. Cold chain logistics has many moving parts which elements include cold storage, cooling systems, cold transport, cold processing, and cold distribution that significantly to support agricultural food supply chain.

In addition, Thailand is the one of countries covered in the global agriculture market. Due to Thailand is the 8th largest exporter of agricultural foods in the world (Ministry of Commerce Report , Department of Trade Negotiations Report, 2024, after the European Union, the united state, China, Canada, Brazil, India, Australia, and Chile which have total value of agricultural foods export to the world market approximately 28,827,272,077.70 million US dollars in January to December 2024, Especially, FTA (free trade agreement) countries such as Asian, China, Japan, South Korea, India, Australia, New Zealand, Chili, Peru, Hong Kong, etc. that continually expanding compare with the

values of export. That is a reason why Thailand is dubbed as the kitchen of the world hence, essentially driven economy by small medium enterprises (SMEs) of agricultural foods supply chain.

From the values of Thailand export, agricultural foods have significantly for country's economic, moreover, Thailand needs technologies depends on industry 4.0 to support all of process from original point (Thailand) to destinations point (partner countries), Significantly, "Cold Chain Logistics" is necessitate for agricultural foods.

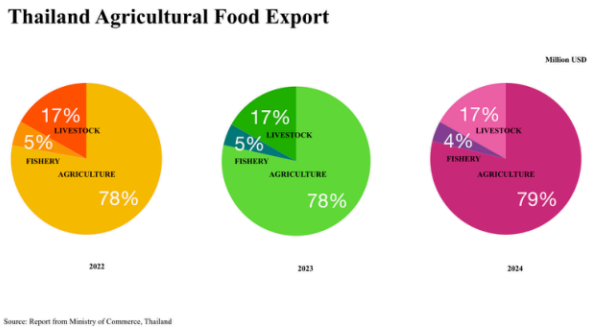

Figure 1: Thailand Agricultural Food Export

Literature review

In recent year, the academics papers mentions cold chain logistics service quality management in logistics 4.0. For instance, (Tang et al., 2024) develop model to access the impact of IoT technologies on cold chain logistics service quality management and information of fresh product e-commerce in logistics 4.0 due to the rapid growth of Internet of things (IoT), Virtual reality (VR), and meta-verse technologies enable customers to purchase fresh food and other products through various e-commerce channels without strict limitation as before. During COVID-19, the explosive growth of demand for fresh agricultural products on e-commerce platform has increased the difficulty of maintaining the greenness and freshness in delivery (Li et al., 2023) Due to the transparency of blockchain technology, all members of the supply chain who join the blockchain can read the whole history of delivery activities. Thus, the information asymmetry saved by the cold chain is eliminated, the supply chain members can obtain real-time freshness and delivery information and the supplier can better control the freshness of fresh agricultural products. The traceability and tamper resistance of blockchain technology can effectively track the historical information of freshness-keeping efforts with timestamps, monitor and feedback the abnormal changes in temperature in the cold chain in real-time, and improve the effect of freshness-keeping efforts. Clearly, accurate labeling of traceability information, such as transportation, manufacture, and storage information, is essential for fresh product quality management. For this reason, many firms in the fresh industry have begun to engage in digital transition by constructing traceability systems to track and trace quality information across the entire transaction process. Blockchain technology is an emerging traceability technology
characterized by decentralization, encryption protection, and openness and transparency (Zhang et al., 2023) Logistics of perishable products is a complex operation (Vilas-Boas J., et al., 2023) It has many

requirements, such as product traceability and monitoring, due to food's high perishability and contamination risks.

The integration of these technologies has been changing how data is collected, shared, and analyzed through the agricultural food products supply chain and has the potential to make a large improvement in fresh food logistics requirements. Logistics integration takes logistics system as the core. Based on the advanced supply chain logistics and warehousing management system, and integrating successful experience in serving leading enterprises in the industry by provides professional cold chain logistics solutions. It helps enterprises standardize all links of cold chain operation, effectively monitor the whole process of cold chain logistics, improve the management level and operation efficiency of cold chain business, and thus improve market competitiveness and customer satisfaction (Bhat and Huang, 2021). In 2023, trend of Thai logistics industry is one of the new target industries (New S curve) to drive the economy in the future which Thailand has geographic advantages are the center of the ASEAN region and is also a connecting point with India and China. Furthermore, it is considered important industries to facilitate the other industries. In particular, the logistics industry is one of the service industries of the future that is included in the 20-years of International development plan (2018-2037 (Office, 2018). in terms of creating competitiveness advantage to enhance the country's potential. After Covid-19, The logistics business in Thailand has a good growth trend. Especially businesses related to e-commerce follows consumer behavior that continues change due to the COVID-19 crisis which has stimulated online trading in consumer products to grow exponentially. Also, the growth opportunities for Thai entrepreneurs be able to expand the market in the temperature-controlled transportation and warehousing business. It also expanded its business into supporting activities, especially technology services. Furthermore, The Economic Intelligence Center from Department of International Trade (2023) illustrate the predictable trend of 2023 (Organization, 2023) in the transportation sector will still face a labor shortage that makes more difficult to respond to customer needs. Hence, logistics service providers should create the transportation plan by using transportation capacity existing to maximum benefit and eliminate inefficiency by comprehensive transition to the digital age is called a digital supply chain 4.0 such as a network of process participants through cloud applications or blockchain technology, vehicle, delivery and warehousing network using sensor technology and IoT solutions, and artificial intelligence (AI) to understand errors and learn how to avoid future mistakes. Etc. A supply chain 4.0 that allows for real-time information sharing and real-time evaluation that helps create transparency in supply chain which make possible to control and monitor each link. Hence, when logistics companies have real-time monitoring, they can better match demand with available human resources or shipping capacity that also leads to a more efficient and flexible in supply chain.

Hence, the cold chain logistics 4.0 has significant role play in part of temperature-controlled transportation and warehousing business. by adopting technologies including real-time tracking and monitoring;, predictive analytics, virtualization, automation and robotics, the Internet of Things (IoT), Industrial Internet of Things (IIoT); cloud computing; Artificial Intelligence (AI), and blockchain technology. Etc. has a significantly impact on the logistics industry through supply chain activities, especially in part of cold chain logistics activities process o keep food quality and food safety of products

and protect food loss and food waste in agricultural foods supply chain. Hence, technologies is very important role play with cold chain logistics as technologies help to develop and improve performance in process of logistics activities.

Research Questions

RQ1: *What are the impact of digital transformation and smart management of supply chain in agricultural food industry in Thailand ?*

RQ2: *What are impact on SMEs 'cold chain agricultural food industry performance in Thailand if minimize food loss and waste (FLW) ?*

Hypothesis

1.Digital transformation adaptation and Smart management

Digital transformation adaptation means as the transformation of business process, culture, and nature of organization to response the customer needs via digital technologies. Especially, the forth industrial revolution, the new information technologies such as Internet of Things, Big data, Block Chain, Cloud Computing, etc., which impact in term of traditional enterprise. (Nasiri et al., 2020).

2. Smart management

Smart management systems aim to building more efficient communication and management systems by emerging based on Internet of Things and Big data which combines engineering technology with management principle that enhances collaboration among industry partners to be competitive in the 21st century (Roy and Roy, 2019).

3. Supply Chain 4.0

Supply Chain 4.0 (the next generation digital supply chain) means the application of Internet of Things, the use of advanced robotics, and the application of advanced analytics of big data in supply chain management which place sensors in everything, create networks everywhere, automate anything, and analyze everything to significantly improve performance and customer satisfaction (Knut Alicke, 2016).

4. Minimize food loss and Waste (FLW)

The research focuses on minimize food loss and food waste in the in agricultural food supply chain to finding provides constructive insight to food companies to incorporate and operationalize recommended measures to minimize food loss and food waste in the agricultural food supply chain (Gokarn and Choudhary, 2021).

Hypothesis 1 (H1) : Digital transformation has positive impact on supply chain 4.0.

Hypothesis 2 (H2) : Smart management has a positive impact on supply chain 4.0.

Hypothesis 3 (H3) : Supply chain 4.0 has a positive impact on minimize food loss and waste (FLW) in SMEs' cold chain agricultural food industry 4.0 performance.

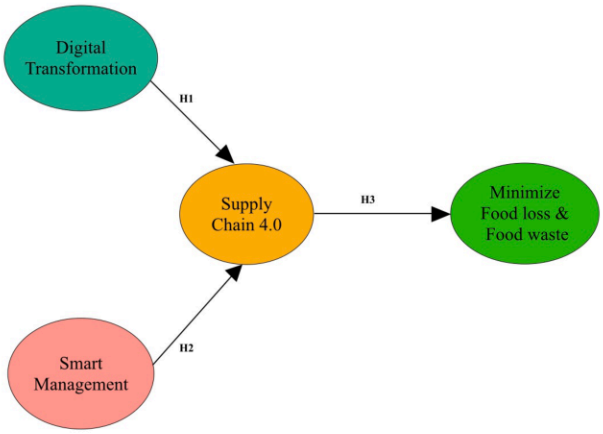

Figure 2. Research model

Research Model

Table 1. Key factors on cold chain logistics 4.0 performance

Key factors	Reference
Digital Transformation	- (Nasiri et al., 2020)
Smart Management	- (Roy and Roy, 2019).
Supply chain 4.0	- (Knut Alicke, 2016)
Minimize Food Loss and Waste (FLW) in SMEs' Cold Chain Agricultural food Industry Performance in Thailand	- (Gokarn and Choudhary, 2021)

Source: Collects by the authors

Research methodology

Data collection

In cold chain logistics 4.0 on agricultural foods industry research, there are pragmatics reasons for the intensive use of survey-based methods and questionnaires to collect data. It allows involvement of various types of agricultural food products within a firm which are convenient for gathering data. The mail surveys allow the researcher to reach upper managerial and executive levels and surveys can

ensure anonymity standardized wording to avoid drawbacks such as interviewer bias (Chao, 2011)

With theoretical support from the literature, a set of questionnaires has been carried out for the actual data collection. The following section illustrate a step-by-step procedure of questionnaire development used in this research.

The target population criteria for this study were “SMEs of agricultural foods industry who used cold chain logistics and understand technologies in industry 4.0 era which support the cold chain logistics 4.0 process. In total 452 effective questionnaires were collected for this research.

Methodology

Due to a model states have two or more relationships, two or more separate regression tests are to be performed in order to test the model fully. Based on this limitation, a more complicated statistical algorithm was developed in early 1970s which essentially incorporated regression analysis with path models and confirmatory factor models to allow test of multiple and interrelated dependence relationships in a simultaneous statistical equation. This was later know as Structural Equation Modeling (SEM) (Joseph F. Hair Jr., 2010, Chao, 2011).

The structure equation modeling (SEM) (Anderson J. & Garbing D., 1988) is a multivariate statistical analysis technique that is used to analyze structural relationships which techniques is the combination of factor analysis and multiple regression analysis. SEM used to analyze the structural relationship between measured variables and latent constructs that the measurement model will has been estimated through a confirmatory factor analysis (CFA) to test the reliability and validity of the measurement model which analyzed to examine the overall model fit. The CFA will has been used to test the all hypothesis through estimating convergence validity with AMOS 22.0 software (Chaopaisarn and Sawangwong, 2022). In the Amos software package, two common type of mechanism are used to detect any misspecification of the hypothesized model, namely: standardized residual and modification indices. According (Joseph F. Hair Jr., 2010) standardized residual are normalized residual which report residuals of individual covariance terms.

Results

Table 2. Measurement model fit indices

CMIN/DF	RMSEA	GFI	AGFI	CFI	TLI	NFI
2.851	0.054	0.941	0.926	0.901	0.934	0.952

Table 3. Results of hypothesis testing

Hypothesis	Path	Estimate	S.E.	P-value	Supported?
H1	Digital Transformation —> Supply chain 4.0	0.516	0.56	***	YES
H3	Smart Management —> Supply chain 4.0	0.631	0.059	***	YES

H6	Supply Chain 4.0 —> Minimize Food Loss and Waste	0.867	0.089	***	YES

Model fitness indices are CMIN/DF (X2/df) = 2.851, RMSEA = 0.054, GFI = 0.941, AGFI = 0.926, CFI = 0.901, TLI = 0.934, NFI = 0.952 are an acceptable fit and three hypothesis were supported.

Conclusion

This research illustrated the literature on cold chains logistics 4.0 on agricultural food supply chain in Thailand by proposing and empirically testing the impact of the theoretical frame work follows digital transformation (Nasiri et al., 2020, Liu et al., 2022), smart management (Roy and Roy, 2019), supply Chain 4.0 (Knut Alicke, 2016), and minimize food loss and food waste (Gokarn and Choudhary, 2021).

Using Structural Equations Model, our data from the survey of SMEs of agricultural foods industry also confirmed these findings. The study represents that digital transformation adaptation and smart management positive impact to supply chain 4.0 moreover, the minimize food loss and food waste that effective to SMEs of agricultural foods industry performance positively.

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