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IMPACT OF INTERNET OF THINGS (IOT) ON ENHANCING TRANSPARENCY AND EFFICIENCY IN BANGLADESH'S AGRI-FOOD SUPPLY CHAIN

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ABSTRACT

Background: The agri-food supply chain in Bangladesh is crucial for the nation's sustenance and economic stability but faces challenges like lack of transparency, inefficiencies, and information asymmetry. The integration of Internet of Things (IoT) technologies offers transformative potential, enhancing the Transparent Physical and Information Flow (PHF) and thereby influencing the Transparency in the Agri-food Supply Chain (TASC).

Objective: This study aims to investigate the impact of IoT integration on PHF and its subsequent effect on TASC in Bangladesh, framed around two core hypotheses: the significant influence of IoT on PHF and the consequent impact of an IoT-enhanced PHF on TASC.

Methods: Employing a comprehensive methodological framework, the study utilized IBM SPSS for exploratory factor analysis and IBM AMOS for confirmatory factor analysis (CFA) and structural equation modeling (SEM) to assess the relationships between IoT technologies, PHF, and TASC. The analysis was based on data collected from 400 respondents in Bangladesh's agriculture sector.

Results and Conclusion: The findings validate both hypotheses, demonstrating a significant and positive impact of IoT technologies on PHF and, subsequently, on TASC. The results highlight the crucial role of IoT in enhancing supply chain transparency and operational efficiency.

Implications of the Research: This research provides empirical evidence on the effectiveness of IoT technologies in addressing transparency issues within the agri-food supply chain. It underscores the potential of IoT to foster improved decision-making, efficiency, and consumer trust in the agricultural sector, particularly in developing contexts like Bangladesh.

Originality/Value: This study contributes original insights into the role of IoT technologies in enhancing the agri-food supply chain's transparency and efficiency. By focusing on the context of Bangladesh, it offers valuable implications for policymakers, industry practitioners, and researchers, emphasizing the transformative potential of IoT in agricultural supply chain management.

Keywords: Internet of Things (loT), Transparent Physical and Information Flow (PHF), Agri-food Supply Chain Transparency (TASC), Structural Equation Modeling (SEM), Bangladesh Agriculture Sector.

IMPACTO DA INTERNET DAS COISAS (IOT) NO AUMENTO DA TRANSPARÊNCIA E EFICIÊNCIA NA CADEIA DE ABASTECIMENTO AGROALIMENTAR DE BANGLADESH

RESUMO

Contexto: A cadeia de abastecimento agroalimentar no Bangladesh é crucial para o sustento e a estabilidade económica do país, mas enfrenta desafios como a falta de transparência, ineficiências e assimetria de informação. A integração das tecnologias da Internet das Coisas (IoT) oferece potencial transformador, potencializando o Fluxo

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Físico e de Informação Transparente (PHF) e influenciando assim a Transparência na Cadeia de Abastecimento Agroalimentar (TASC).

Objetivo: Este estudo visa investigar o impacto da integração da IoT no PHF e seu efeito subsequente no TASC em Bangladesh, enquadrado em torno de duas hipóteses principais: a influência significativa da IoT no PHF e o conseqüente impacto de um PHF aprimorado pela IoT no TASC.

Métodos: Empregando uma estrutura metodológica abrangente, o estudo utilizou IBM SPSS para análise fatorial exploratória e IBM AMOS para análise fatorial confirmatória (CFA) e modelagem de equações estruturais (SEM) para avaliar as relações entre tecnologias IoT, PHF e TASC. A análise baseou-se em dados recolhidos junto de 400 inquiridos no setor agrícola do Bangladesh.

Resultados e Conclusão: Os resultados validam ambas as hipóteses, demonstrando um impacto significativo e positivo das tecnologias IoT no PHF e, posteriormente, no TASC. Os resultados destacam o papel crucial da IoT no aumento da transparência da cadeia de abastecimento e da eficiência operacional.

Implicações da investigação: Esta investigação fornece provas empíricas sobre a eficácia das tecnologias IoT na abordagem de questões de transparência na cadeia de abastecimento agroalimentar. Salienta o potencial da IoT para promover uma melhor tomada de decisões, eficiência e confiança do consumidor no setor agrícola, particularmente em contextos em desenvolvimento como o Bangladesh.

Originalidade/Valor: Este estudo contribui com insights originais sobre o papel das tecnologias IoT no aumento da transparência e eficiência da cadeia de abastecimento agroalimentar. Ao centrar-se no contexto do Bangladesh, oferece implicações valiosas para os decisores políticos, profissionais da indústria e investigadores, enfatizando o potencial transformador da IoT na gestão da cadeia de abastecimento agrícola.

Palavras-chave: Internet das Coisas (loT), Fluxo Físico e de Informação Transparente (PHF), Transparência da Cadeia de Abastecimento Agroalimentar (TASC), Modelagem de Equações Estruturais (SEM), Setor Agrícola de Bangladesh.

IMPACTO DEL INTERNET DE LAS COSAS (IOT) EN LA MEJORA DE LA TRANSPARENCIA Y LA EFICIENCIA EN LA CADENA DE SUMINISTRO AGROALIMENTARIO DE BANGLADESH

RESUMEN

Antecedentes: La cadena de suministro agroalimentario en Bangladesh es crucial para el sustento y la estabilidad económica de la nación, pero enfrenta desafíos como falta de transparencia, ineficiencias y asimetría de información. La integración de las tecnologías de Internet de las cosas (IoT) ofrece un potencial transformador, mejorando el flujo físico y de información transparente (PHF) y, por lo tanto, influyendo en la transparencia en la cadena de suministro agroalimentario (TASC).

Objetivo: Este estudio tiene como objetivo investigar el impacto de la integración de IoT en PHF y su efecto posterior en TASC en Bangladesh, enmarcado en dos hipótesis centrales: la influencia significativa de IoT en PHF y el impacto consiguiente de un PHF mejorado con IoT en TASC.

Métodos: Empleando un marco metodológico integral, el estudio utilizó IBM SPSS para análisis factorial exploratorio e IBM AMOS para análisis factorial confirmatorio (CFA) y modelado de ecuaciones estructurales (SEM) para evaluar las relaciones entre las tecnologías IoT, PHF y TASC. El análisis se basó en datos recopilados de 400 encuestados en el sector agrícola de Bangladesh.

Resultados y conclusión: Los hallazgos validan ambas hipótesis, demostrando un impacto significativo y positivo de las tecnologías de IoT en PHF y, posteriormente, en TASC. Los resultados resaltan el papel crucial del IoT en la mejora de la transparencia de la cadena de suministro y la eficiencia operativa.

Implicaciones de la investigación: Esta investigación proporciona evidencia empírica sobre la efectividad de las tecnologías de IoT para abordar cuestiones de transparencia dentro de la cadena de suministro agroalimentaria. Subraya el potencial de la IoT para fomentar una mejor toma de decisiones, la eficiencia y la confianza de los consumidores en el sector agrícola, particularmente en contextos en desarrollo como Bangladesh.

Originalidad/Valor: Este estudio aporta conocimientos originales sobre el papel de las tecnologías de IoT en la mejora de la transparencia y la eficiencia de la cadena de suministro agroalimentaria. Al centrarse en el contexto de Bangladesh, ofrece implicaciones valiosas para los formuladores de políticas, los profesionales de la industria y los investigadores, enfatizando el potencial transformador de la IoT en la gestión de la cadena de suministro agrícola.

Palabras clave: Internet de las Cosas (loT), Flujo Físico y de Información Transparente (PHF), Transparencia de la Cadena de Suministro Agroalimentaria (TASC), Modelado de Ecuaciones Estructurales (SEM), Sector Agrícola de Bangladesh.

1 INTRODUCTION

The contemporary landscape of the agri-food supply chain in Bangladesh stands at a critical juncture, with increasing demands for transparency and efficiency. This paper delves into the pivotal role of Internet of Things (IoT) technologies in revolutionizing the Transparent Physical and Information Flow (PHF) within the Agri-food Supply Chain (TASC), a development with far-reaching implications for Bangladesh's agricultural sector. The infusion of IoT into PHF paves the way for a new era of transparency and operational excellence in TASC, addressing longstanding challenges and unlocking new opportunities.

The agri-food supply chain is an intricate network that is crucial for the sustenance and economic stability of Bangladesh. It involves various stakeholders, including farmers, distributors, and consumers, each of whom relies on the efficiency and reliability of this supply chain (Islam & Rashid, 2022). Bangladesh's Agri-food Supply Chain: Challenges and Opportunities. However, this sector has been marred by issues such as lack of transparency, inefficiencies, and information asymmetry (Kraft & Kellner, 2022), which not only undermine trust but also impede the sector's overall performance.

In this context, the integration of IoT technologies emerges as a transformative force. IoT's potential to enhance the visibility and interoperability of the supply chain is profound. By embedding sensors and smart devices at various points in the supply chain, stakeholders can access real-time data, enabling better decision-making and enhancing the flow of physical goods and information (Saurabh & Dey, 2021). This technological intervention is pivotal for PHF, as it ensures the seamless flow of information and materials, thus fostering transparency and efficiency.

The significance of TASC in Bangladesh cannot be overstated. A transparent supply chain not only boosts consumer confidence but also enhances the competitiveness of the agricultural sector on a global scale. It ensures that the products are traceable, safe, and produced under fair conditions, aligning with the growing global demand for ethical and transparent production practices (Kouhizadeh & Sarkis, 2018).

The purpose of this paper is to investigate the impact of IoT integration on PHF and, subsequently, its effect on TASC in Bangladesh. The research is structured around two hypotheses: first, that the integration of IoT technologies significantly enhances PHF; and second, that an IoT-infused PHF substantially contributes to the transparency of TASC. These hypotheses are grounded in the belief that technology can be a lever for systemic change, driving improvements across the supply chain that benefit all stakeholders.

To address these research questions, the study employs a comprehensive methodological framework. An initial factor analysis was conducted using IBM SPSS to ascertain the reliability of the survey responses, employing Exploratory Factor Analysis and Internal Reliability Cronbach Alpha analysis. Subsequently, the model's fitness was assessed through Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) using IBM AMOS software. The culminating hypothesis path analysis revealed positive impacts, corroborating the proposed hypotheses and underscoring the efficacy of IoT technologies in enhancing TASC through improved PHF.

In conclusion, the integration of IoT technologies in the agri-food supply chain presents a promising avenue to address the pressing need for transparency and efficiency in Bangladesh's agricultural sector. By harnessing the power of IoT to enhance PHF, stakeholders across the supply chain can benefit from improved transparency, which in turn fosters trust, efficiency, and sustainability. This study contributes to the burgeoning body of literature on the intersection of technology and supply chain management, offering valuable insights for policymakers, industry practitioners, and researchers alike.

2 LITERATURE REVIEW

This section provides an in-depth examination of the existing body of literature, focusing on three core areas: Internet of Things (IoT) technologies, Transparent Physical and Information Flow (PHF), and Transparency in Agri-food Supply Chain (TASC). By exploring these domains, this review aims to establish a foundational understanding of the current state of knowledge and identify the gaps that this study intends to address.

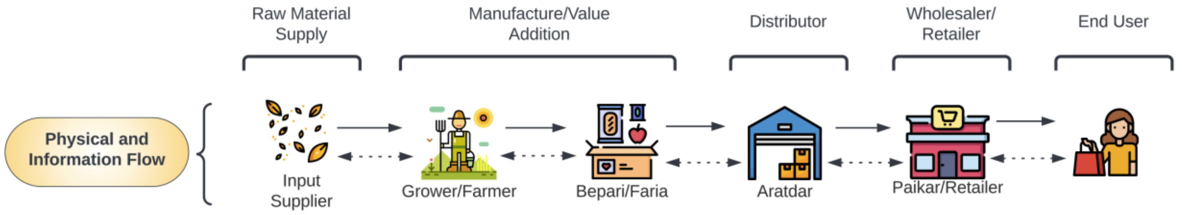
2.1 PHYSICAL AND INFORMATION FLOW OF AGRI-FOOD SUPPLY CHAIN IN BANGLADESH

Transparent Physical and Information Flow (PHF) is pivotal in the agri-food supply chain, ensuring stakeholders receive precise and timely data, which fosters trust and collaboration. In the context of Bangladesh's Agricultural Supply Chain (ASC), the role of intermediaries is prominent. These intermediaries act as crucial connectors between farmers and consumers. Previous studies highlight that the Bangladesh ASC is characterized by a dense network of middlemen, who capture a significant portion of the consumer price as profit (Hasan, Habib, Mohamed, & Tewari, 2023). A report from December 2023 in The Financial Express revealed that the price of winter vegetables spikes by 80 to 450 percent by the time they reach urban retailers, compared to their initial farmgate prices. For instance, although the Department of Agricultural Marketing (DAM) estimates the production cost of cauliflower at Tk 11, its urban retail price can soar to Tk 45 - Tk 50, marking an increase of 300 to 350 percent. This price surge is attributed to the produce's progression through several intermediaries, often around five, before it reaches the consumer, drastically elevating the price from the farmer's selling point (The Financial Express, 2024).

Describing the agri-food supply chain process in Bangladesh: Input Suppliers provide essential raw materials, followed by growers or farmers who cultivate the agri-foods and pass them on to Bepari/Faria. Farias, often landless laborers or small farmers engaged in part-time farming, are small-scale traders who operate in a few local markets dealing with limited quantities of produce. They buy from farmers and sell to Beparis, who are key players in the supply chain, purchasing from farmers or Farias, sorting, and packaging the goods, then selling to Aratdars. Aratdars act as intermediary agents, providing storage and handling a fixed commission for connecting Beparis and retailers. They play a central role in the storage and distribution of perishable goods to retailers, the final link in the chain, who then sell to the end consumers (Hasan & Habib, 2022). This entire sequence outlines the Physical and Information Flow in Bangladesh's ASC as depicted in Figure 1.

Figure 1

Physical and Information Flow of Agri-Food Supply Chain (ASC) in Bangladesh



2.2 INTERNET OF THINGS (IOT) TECHNOLOGIES FOR ASC

The Internet of Things (IoT) represents a significant technological advancement, characterized by the interconnectivity of physical devices through the internet. These devices, equipped with sensors and actuators, are capable of collecting and exchanging data, thereby facilitating a new level of interaction between the digital and physical worlds (Liu, Shao, Wu, & Qiao, 2021). In the context of the agri-food supply chain, IoT technologies offer transformative potential, enabling real-time tracking, monitoring, and management of resources, which can lead to enhanced efficiency and decision-making.

Numerous scholars, like Lankhorst (2019), highlight the necessity of architectural frameworks to manage intricate organizations or systems effectively. An information system's architecture is an intricate blend of various information needs, system elements, and supportive technologies. System architecture is essentially the core framework of a system, encompassing its components and their interactions, which collectively fulfill the system's objectives (Xuemin, Zhiming & Ping, 2012). The traceability system architecture model, depicted in Figure 2 from the work of Purwandoko, Seminar, Sutrisno, & Sugiyanta (2019), shows a good example of a IoT system for ASC.

Figure 2

IoT-Based Agri-Food Traceability System Architecture

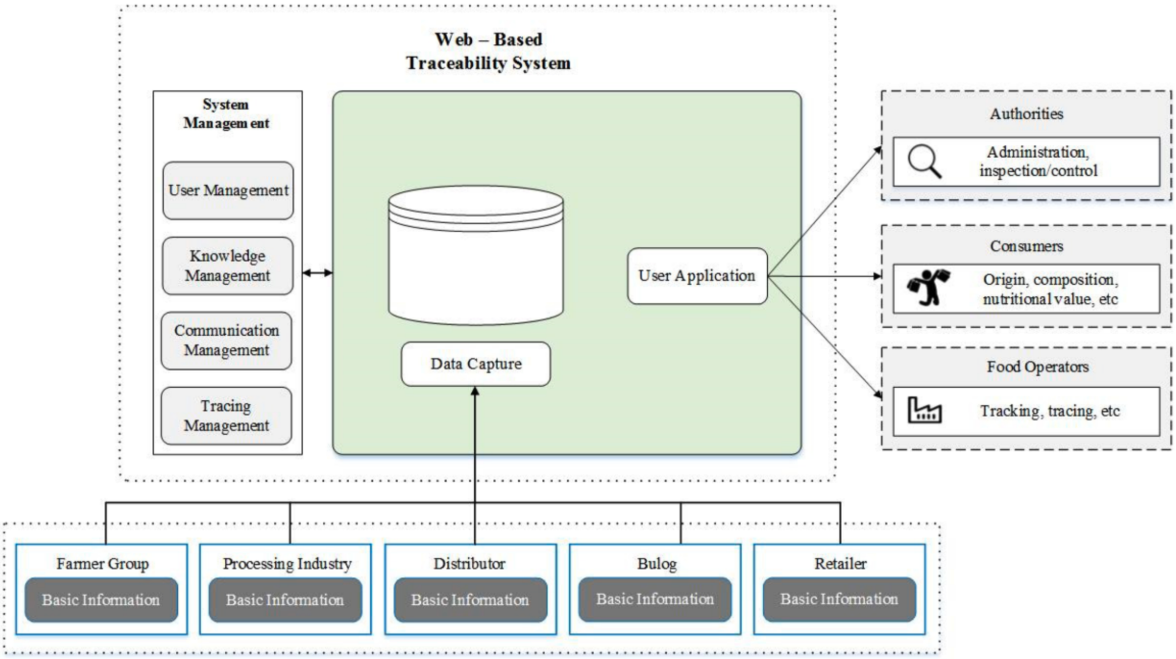


Figure 2 showcases the IoT-Based Agri-Food Traceability System Architecture, detailing the application systems within the information system architecture, their roles in supporting supply chain operations, essential application concepts, the logical arrangement of information systems for a comprehensive overview of inter-system information exchange, and the design modules of the information system. The architecture includes various management systems, such as user management, knowledge management, communication management, and traceability management, essential for an agri-food traceability framework. The user management component allows different stakeholders, like the government, consumers, and food proprietors, to access system administration features. In the agroindustry's traceability system, knowledge management aids in decision-making regarding supplier selection and customer relationship management. Traceability management enables product tracking, while communication management facilitates interactions among stakeholders. Moreover, the system employs a QR Code as a data collection tool, where data recorded is stored on the traceability server, either locally or on the cloud.

Earlier research also demonstrates that incorporating Internet of Things (IoT) technology within the agri-food supply chain offers a promising solution to the complex issues in Bangladesh ASC (Hasan, Habib, & Mohamed, 2023a). This integration aims to enhance traceability, boost food safety and quality, reduce food wastage, allow precise demand forecasting, and optimize inventory management.

2.3 TRANSPARENCY IN AGRI-FOOD SUPPLY CHAIN (TASC)

Transparency in the agri-food supply chain is increasingly recognized as a critical factor for ensuring food safety, quality, and sustainability. It involves the open sharing of information regarding the origins, processing, handling, and distribution of food products, which is essential for building consumer trust and compliance with regulatory requirements. Research indicates that enhanced transparency in TASC can lead to improved outcomes in terms of food safety, environmental sustainability, and social responsibility.

The literature underscores the synergistic relationship between IoT technologies and PHF in enhancing TASC. IoT's capacity to provide real-time, accurate data can significantly improve the transparency and efficiency of PHF, which in turn, positively impacts the transparency and trustworthiness of the entire agri-food supply chain. However, while the potential benefits are substantial, the literature also highlights challenges such as data security, privacy concerns, and the need for robust frameworks to maximize the benefits of IoT in enhancing TASC (Rejeb, Keogh, Zailani, Treiblmaier, & Rejeb, 2020).

The literature review clearly establishes a connection between the Internet of Things (IoT), Physical and Information Flow (PHF), and the Traceability of the Agri-Food Supply Chain (TASC). It highlights how IoT technology can revolutionize the agri-food supply chain by boosting transparency and efficiency. Specifically, in Bangladesh, the lack of a transparent agri-food supply chain presents numerous challenges, including issues with traceability, ensuring food safety and quality, reducing food wastage, forecasting demand accurately, and managing inventory effectively in the Bangladesh Agri-Food Supply Chain (ASC) system. By integrating IoT technology, there's potential to address these challenges effectively.

However, the discussion also points out the necessity for additional research to overcome these obstacles and fully leverage the advantages of IoT within this context. This sets a foundation for this study to contribute valuable insights and advancements in the field.

3 METHODOLOGY

This study adopts an experimental design approach to explore the relationships between Internet of Things (IoT) technologies, Transparent Physical and Information Flow (PHF), and Transparency in the Agri-food Supply Chain (TASC) within the context of Bangladesh's agricultural sector. This methodology section outlines the research design, instruments, and data analysis methods employed to achieve the research objectives and test the proposed hypotheses.

3.1 RESEARCH DESIGN

The experimental design enables the isolation and analysis of the effects of IoT technologies (independent variable) on PHF (mediator variable) and subsequently on TASC (dependent variable). The variables were identified through comprehensive secondary data analysis and were further examined using primary data. The study's population comprises stakeholders in Bangladesh's agriculture sector, with a sample size of 400 respondents determined using the Taro Yamane method (Yamane, 1967). The formula:

$$n = \frac{N}{1+N(e)^2} \qquad (1)$$

Was applied, where:

'n' is the sample size, 'N' is the population size, and 'e' is the margin of error. With a population exceeding 100,000 and a chosen margin of error, the calculated sample size was 400.

Data were collected using a self-administered questionnaire distributed through online Google Forms and face-to-face interviews, ensuring a broad and diverse respondent base. The study utilized probability simple random sampling to enhance the representativeness of the sample (Sileyew, K. J., 2019).

3.2 INSTRUMENTS

The questionnaire employed a Likert scale ranging from 1 (strongly agree) to 5 (strongly disagree) to gauge respondents' perceptions and experiences regarding IoT, PHF, and TASC (Kothari, 2019). This scale is widely recognized for its effectiveness in capturing the intensity of respondents' attitudes or feelings toward given statements (Hair, Hult, Ringle, & Sarstedt, 2017).

3.3 DATA ANALYSIS

The data analysis was conducted in four sequential stages:

- Preliminary Data Examination: Initial data screening was performed using Microsoft Excel and IBM SPSS to detect any anomalies or outliers, setting the stage for a robust analysis (Bryman, 2016);
- Structural Model Analysis: IBM AMOS software was utilized for Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM), enabling the exploration of complex variable relationships and the assessment of the proposed model's fit (Hutchcroft, 2023);
- Hypothesis Testing and Path Analysis: The hypotheses were tested, and path analysis was conducted using IBM AMOS, providing a detailed examination of the direct and indirect effects among the variables (Dovbischuk, 2023).

This comprehensive methodological approach ensures a thorough examination of the IoT's impact on PHF and, subsequently, on TASC in the Bangladeshi agriculture sector, contributing valuable insights to the field.

4 RESULTS

In this section, we present the outcomes of Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM), applied to assess the relationships between IoT technologies, Transparent Physical and Information Flow (PHF), and Transparency in the Agri-food Supply Chain (TASC) in Bangladesh. This section details the reliability analysis, highlighting the internal consistency and construct validity through EFA, and the model fit indices from CFA and SEM, underscoring the theoretical framework's robustness in explaining the dynamics within the agri-food supply chain influenced by IoT integration. Then moved to hypotheses analyzed to further understand the relationship between our variables.

4.1 RELIABILITY ANALYSIS

The Exploratory Factor Analysis (EFA) was employed to unearth the inherent relationships among the survey items, as advised by Hair et al. (2006). This technique is essential in identifying how items correlate with specific factors within the constructs, guiding the optimal number of factors to aptly represent the data (Hair, Black, Babin, & Anderson, 2019).

4.1.1 Convergent Validity and Internal Consistency:

Convergent validity, a key aspect of construct validity, was assessed by examining factor loadings, Average Variance Extracted (AVE), and Composite Reliability (CR), following guidelines by Hair et al. (2019).

- **Factor Loadings:** All retained items showed factor loadings greater than 0.4, the minimum threshold, with the use of SPSS employing Varimax rotation for clearer factor interpretation;
- **Average Variance Extracted (AVE):** The AVE values surpassed 0.5, indicating that the constructs explain more than half of the variance of their indicators, reflecting strong convergent validity;
- **Composite Reliability (CR):** CR values were above 0.7, suggesting good internal consistency, thus reinforcing the reliability of the construct measures.

Internal Reliability:

Utilizing Cronbach's alpha, all constructs displayed values greater than 0.7, affirming high reliability (Scholtes, Terwee & Poolman, 2011). This indicates that the survey instrument possesses a high level of internal consistency.

Table 1

Exploratory Analysis of the Variables

Construct	Item	Internal reliability Cronbach alpha	Convergent validity: Factor loading (>0.4)	Composite reliability (>0.7)	Average variance extracted (>0.5)
RMS (5 items)	RMS_1	0.787	0.809	0.855	0.546
	RMS_2		0.672		
	RMS_3		0.571		
	RMS_4		0.786		
	RMS_5		0.824		
FAR (3 items)	FAR_2	0.792	0.834	5.149	0.633
	FAR_3		0.821		
	FAR_4		0.727		
BNF (5 items)	BNF_1	0.804	0.810	0.860	0.553
	BNF_2		0.662		
	BNF_3		0.710		
	BNF_4		0.731		
	BNF_5		0.794		
ARA (3 items)	ARA_1	0.740	0.795	5.191	0.634
	ARA_3		0.742		
	ARA_5		0.849		
RET (5 items)	RET_1	0.798	0.783	0.862	0.556
	RET_2		0.738		
	RET_3		0.691		
	RET_4		0.672		
	RET_5		0.834		
CON (3 items)	CON_1	0.766	0.887	0.861	0.676
	CON_2		0.853		
	CON_3		0.716		
IOT (4 items)	IOT_1	0.952	0.941	0.958	0.849
	IOT_2		0.922		
	IOT_3		0.909		
	IOT_4		0.914		
PHF (2 items)	PHF_1	0.917	0.904	0.894	0.808
	PHF_2		0.894		
TASC (4 items)	TASC_1	0.911	0.827	0.917	0.735
	TASC_2		0.852		
	TASC_3		0.882		
	TASC_4		0.868		

The EFA results in the table 1 showed factor loading scores between 0.571 and 0.941, surpassing the recommended level of 0.40 (Hair et al., 2019). With four items dropped (FAR_1, FAR_5, ARA_2, ARA_4), the AVE and CR values also met the required thresholds. High

Cronbach's alpha scores across all constructs confirmed their reliability, setting a solid foundation for further analysis.

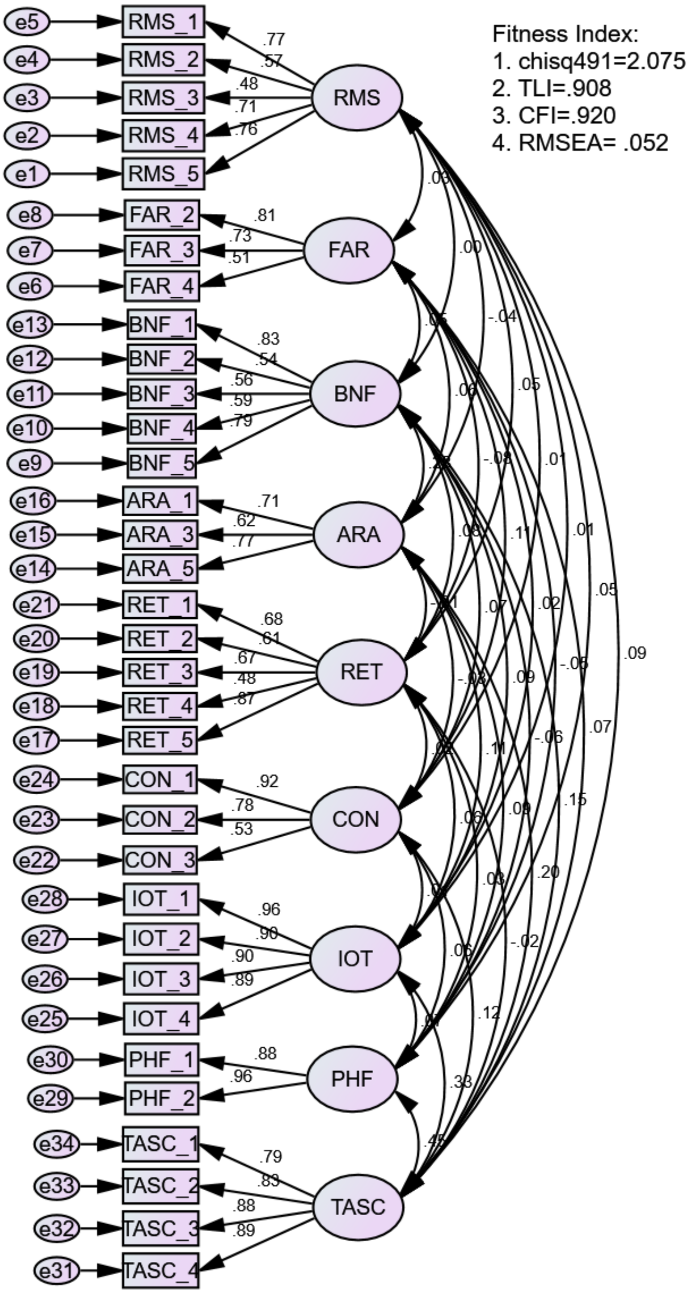
4.2 CRITERIA FOR FIT INDEX

4.2.1 Confirmatory Factor Analysis (CFA)

Following EFA, CFA was conducted to verify the factor structure. Acceptable fit indices, as suggested by (Schumacker & Lomax, 2016), include CMIN/DF less than 5.0, CFI and IFI exceeding 0.90, and RMSEA below 0.10.

Figure 3

First Order Measurement Model Based on Variables



The First Order Model's fit indices shows in figure 3, such as Chisq/df = 2.075, TLI = 0.908, CFI = 0.920, and RMSEA = 0.052, demonstrated a good fit, aligning the model closely with the collected data

4.2.2 Second Order Mediating Model

The study included two second order models to accommodate the mediating and dependent variables.

Figure 4

Results of Order Measurement Model [Model1]

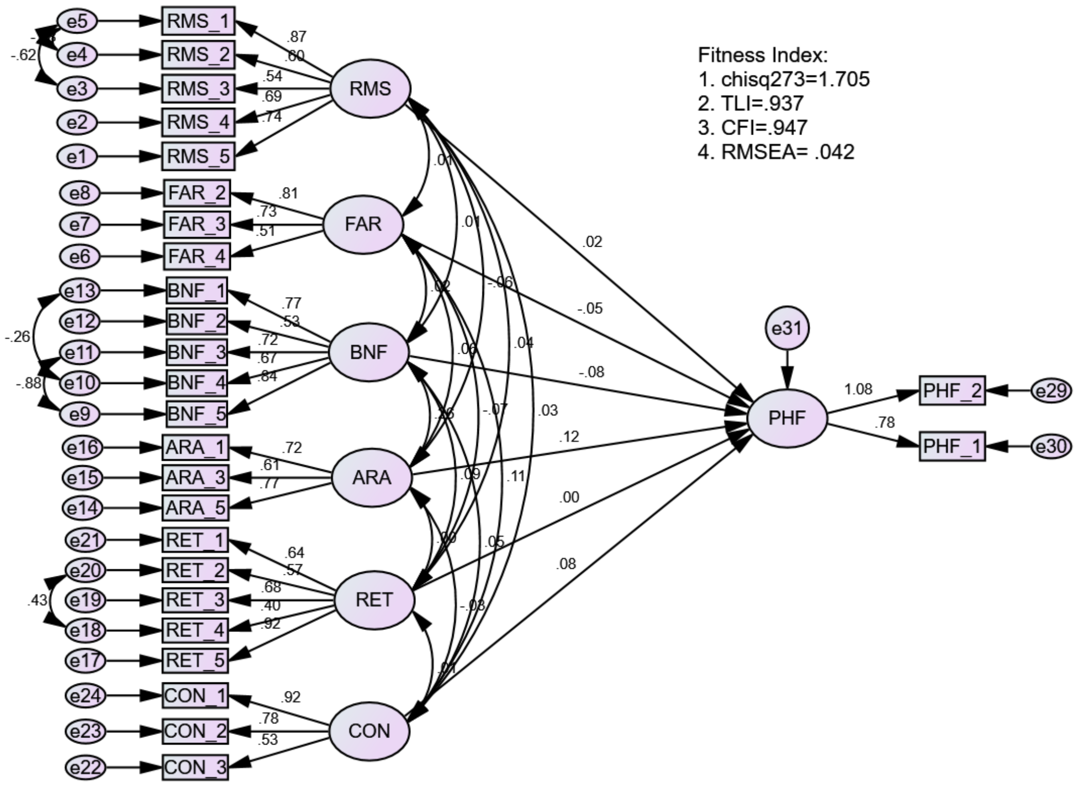
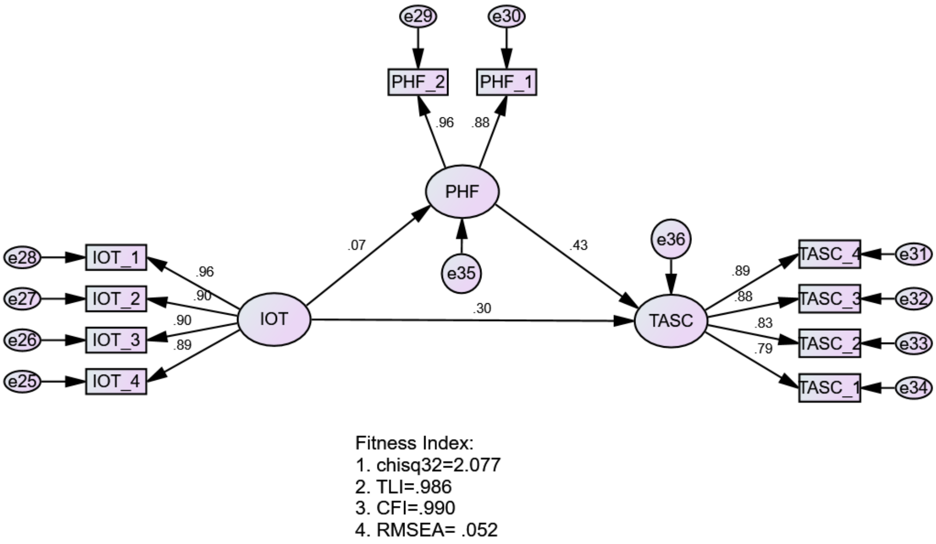


Figure 5

Results of Second Order Measurement Model [Model2]



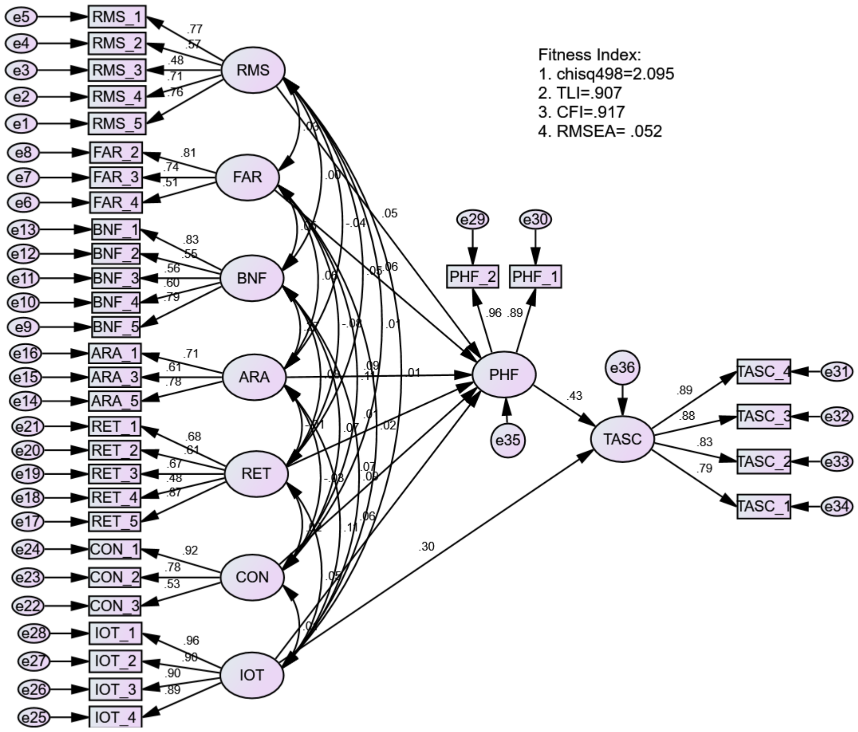
Both models exhibited fit indices that confirm the suitability of the models to the data.

4.2.3 Structural Equation Model (SEM)

The SEM segment examined the structural model against the overall measurement model to ensure consistency with the proposed theoretical framework.

Figure 6

Results of Structural Model



The initial structural model displayed in the figure 6, Chisq/df = 2.095, TLI = 0.907, CFI = 0.917, and RMSEA = 0.052, indicating a good fit and validating the model's appropriateness for the data under study

These analyses collectively affirm the robustness of the measurement model, paving the way for a nuanced understanding of the relationships between IoT technologies, PHF, and TASC in the context of Bangladesh's agri-food supply chain.

4.3 HYPOTHESIS ANALYSIS

The proposed framework and its associated hypotheses were analyzed using Structural Equation Modeling (SEM). This analysis helped determine the strength and significance of the paths in the proposed model.

Figure 7

Results of the Hypotheses

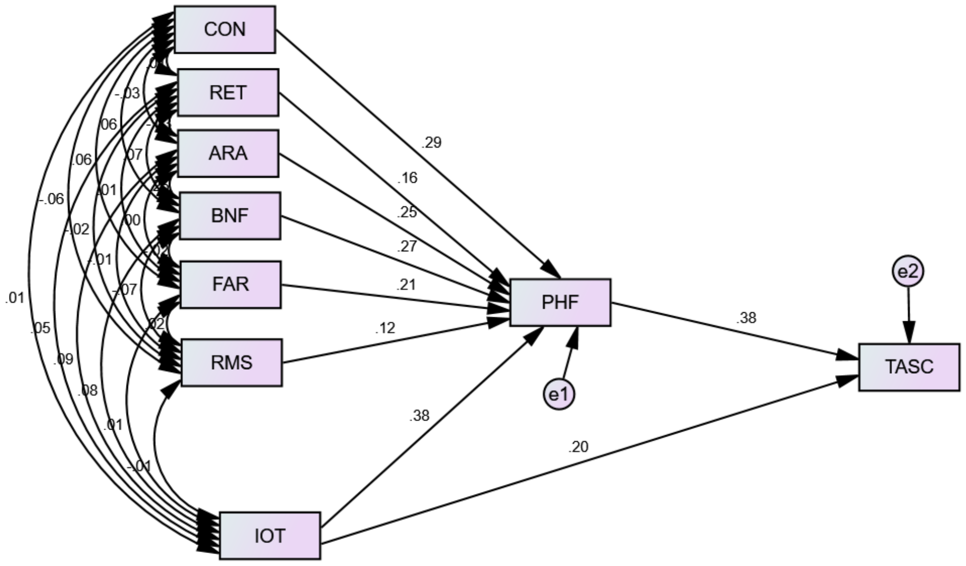


Figure 7 illustrates the SEM results, detailing significant and non-significant paths, including direct and mediation relationships within the proposed framework. The key findings from these analyses are summarized table 2 below:

Table 2

Hypothesis Testing Summary

Hypotheses	Paths	Estimate (β)	S.E.	C.R.	p	Results*
H1: There is a significant relationship between Internet of Things (IoT) technologies integration and Transparent Physical and Information Flow (PHF).	IOT---> PHF	0.128	0.011	11.210	***	Supported
H2a: There is a significant relationship between IoT imputed Physical and Information Flow (PHF) and Transparency in Agri-food Supply Chain (TASC).	PHF---> TASC	0.792	0.099	7.973	***	Supported
H2a: There is a significant relationship between Internet of Things (IoT) technologies integration and Transparency in Agri-food Supply Chain (TASC).	IOT ---> TASC	0.138	0.033	4.178	***	Supported

* Note: *: p< 0.05, **: p<0.01, ***: p<0.001

- **Hypothesis 1 (H1):** There is a significant relationship between Internet of Things (IoT) technologies integration and Transparent Physical and Information Flow (PHF). The analysis showed a positive and significant impact of IoT technologies on PHF (β = 0.128; CR = 11.210; $p < 0.001$), supporting H1;
- **Hypothesis 2a (H2a):** There is a significant relationship between IoT-imputed Physical and Information Flow (PHF) and Transparency in Agri-food Supply Chain (TASC). The findings indicated a strong and significant influence of PHF on TASC (β = 0.792; CR = 7.973; $p < 0.001$), thus H2a is supported;
- **Hypothesis 2b (H2b):** There is a significant relationship between Internet of Things (IoT) technologies integration and Transparency in Agri-food Supply Chain (TASC). The analysis revealed that IoT technologies have a significant direct impact on TASC (β = 0.138; CR = 4.178; $p < 0.001$), endorsing H2b.

The examination of these hypotheses sheds light on the integral roles that IoT technologies can in fact make the agri-food supply chain physical and information flow transparent which play a vital role in enhancing transparency within the Agri-food Supply Chain; thus complimenting the research of Hasan, Habib, & Mohamed (2023a). The consistency in the support for these hypotheses underscores the robustness of the proposed model and the validity of the findings.

5 CONCLUSION

This study delves into the pivotal role of Internet of Things (IoT) technologies in enhancing the Transparent Physical and Information Flow (PHF) within the Agri-food Supply Chain (TASC), with a specific focus on Bangladesh's agricultural sector. The research findings corroborate the hypothesis that IoT integration significantly bolsters PHF, which in turn, markedly improves the transparency in TASC. This research contributes to the existing body of knowledge by providing empirical evidence on the effectiveness of IoT technologies in resolving transparency issues within the agri-food supply chain, a critical sector for Bangladesh's economy and food security.

5.1 SUMMARY OF MAIN FINDINGS

- **Impact of IoT on PHF:** The study's results affirm that the integration of IoT technologies significantly enhances PHF, underlining the transformative potential of IoT in streamlining and making the supply chain more transparent and eficiente;
- **PHF's Influence on TASC:** The analysis reveals that improved PHF, facilitated by IoT technologies, significantly contributes to the transparency of the agri-food supply chain, thus enhancing trust among stakeholders and potentially leading to better consumer confidence and market competitiveness;
- **Direct Impact of IoT on TASC:** Beyond influencing TASC through PHF, IoT technologies also have a direct positive impact on TASC, underscoring the multifaceted benefits of IoT integration in the supply chain.

5.2 INTEGRATION OF IOT AND ITS BROAD IMPLICATIONS

The study highlights how IoT technology can revolutionize the agri-food supply chain by boosting transparency and efficiency. Particularly in Bangladesh, the lack of a transparent agri-food supply chain presents numerous challenges, such as issues with traceability, food safety and quality assurance, reduction of food wastage, accurate demand forecasting, and effective inventory management. By integrating IoT technology, there is a substantial potential to effectively address these challenges, paving the way for a more reliable, efficient, and transparent supply chain.

5.3 LIMITATIONS OF THE STUDY

While the study provides insightful findings, it is not without limitations. The research is constrained by its geographical focus on Bangladesh, which may limit the generalizability of the results to other contexts or regions. Additionally, the study's reliance on a specific sample size and methodology may introduce biases or limit its applicability to other supply chain environments or industries.

5.4 SUGGESTIONS FOR FUTURE RESEARCH

Future research could explore the integration of IoT with other technologies, conduct comparative studies in different regions, undertake longitudinal analyses, and examine stakeholder perspectives to provide a more comprehensive understanding of IoT's impact on agri-food supply chains globally.

5.5 CONCLUSION

In conclusion, this study underscores the significant potential of IoT technologies to enhance transparency and efficiency in the agri-food supply chain, particularly in the context of Bangladesh. By fostering a more transparent physical and information flow, IoT integration holds the promise of transforming the agri-food supply chain into a more reliable, efficient, and consumer-trustworthy system. The findings not only contribute to academic discourse but also offer practical insights for policymakers, industry practitioners, and technologists aiming to leverage IoT for sustainable and transparent supply chain practices.

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